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# DEVELOPMENT OF ARTIFICIAL EARTH SATELLITE SIMULATION SOFTWARE FOR FUTURE RADIO TELESCOPES IN INDONESIA

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*Abstract.* In the near future, four radio telescopes will be installed in Indonesia. Besides the astronomical purposes, these telescopes are expected to support the ground station for tracking the Artificial Earth Satellites (AES). In this study, we focus on the development of AES simulation software, named AESSIMS, that can be used to aid Indonesian radio telescope engineers in tracking the AES. This software is interactive and web-based. It can track the AES position in real time as well as predict the position for the near future. This software provides information about when a satellite signal can be acquired and lost, which can be beneficial for radio telescopes to establish communication with the satellite. We visualize the use of this software by conducting a simulation of satellite tracking by Indonesian future radio telescopes. Three Indonesian satellites named LAPAN-A1/TUBSAT, LAPAN-A2/ORARI, and LAPAN-A3/IPB are considered in the simulation. This study demonstrates that AESSIMS simulation results for Indonesian satellites and radio telescopes are consistent with the results obtained from already existing satellite tracking simulation software.

*Key words*: Satellite, orbit, simulation, radio telescope.

## 1. INTRODUCTION

To keep up with modern development of astronomy, Indonesian astronomers have explored the development of new observatories in their country at suitable locations for multi-wavelength observations within the framework of the National Observatory (Hidayat *et al.*, 2012). Radio waves are the main choice for reaching the multi-wavelength domain because they have become established science, with technology that is also mature and now relatively inexpensive. Currently, a new observatory called the Timau National Observatory is being built on Timor island near Mount Timau. Besides its optical telescope, there is a plan to build a radio telescope in that observatory as mentioned on Master Plan of National Observatory (Mumpuni *et al.*, 2017). The type of radio telescope that have been proposed in Timau is a 20-meter class of single dish with the frequency range of 1 up to 50 GHz. The dish is expected to be used not only for single dish observation, but also as a part of interferometry and Very Long Baseline Interferometry (VLBI) collaboration. The site is large enough to include radio telescopes, and tests have shown that the radio astronomical signals in the area are undisturbed and ideal for constructing a radio telescope (*e.g.*, Hidayat *et al.*, 2014; Sitompul *et al.*, 2021; Nurul Huda *et al.*, 2021).

On the other hand, Indonesia recently has plans to build a 13-meter diameter radio telescope at Bosscha Observatory, Bandung. This telescope will be part of an international project called VLBI Global Observing System or VGOS (Petrachenko *et al.*, 2009). The telescope is expected to provide essential capabilities in monitoring Earth Orientation Parameters and will play a significant role in establishing Celestial/Terrestrial reference frames. Additionally, the new telescope has the potential to track satellites.

Moreover, telecommunication antennae in Jatiluhur (West Java) and Parepare (South Sulawesi) are currently being converted into radio telescopes. Indeed, the telecommunication antennas in Jatiluhur was designed for receiving the information of communication satellite and has diameter 18.3 meter. Meanwhile, the system in Parepare was designed for receiving and recording the Earth observation data of the synthetic aperture radar, the optical sensor, and satellite telemetry data. It has 11-meter diamater that consists of a main reflector and a sub-reflector with frequency selective reflecting surface that used to receive satellite data.

It is known that the radio telescopes, besides its astronomical purposes, can be used to observe Artificial Earth Satellites (AES) whether as a single disk or as a network (see *e.g.*, Huang *et al.*, 2011; Klügel *et al.*, 2015; Hellerschmied *et al.*, 2018). Satellites emit various radio signals, such as those used for communication and navigation, that can be detected by radio telescopes on the ground. By observing and analyzing these signals, radio telescopes can determine the precise location, speed, and other parameters of the satellites they are tracking.

AES has dramatically increased in number since 1950s. Up to now, there are thousands satellites that were launched successfully into orbit. AES has various missions that have an essential role in human life, such as navigation, remote sensing, communication, and defense (see *e.g.*, Rumadi *et al.*, 2020; Tang, Wang, and Chen, 2016; Ji-yang *et al.*, 2016; Abdelsalam *et al.*, 2019; Nicholas, Tkacheff, and Kuhns, 2016). These missions determine the AES configuration, such as the architecture, batteries, sensors, altitude controller, and communication system (Baturkin, 2005).

Indonesia needs AES for several purposes such as for amateur radio communication, disaster mitigation, and agriculture. Up to now, there are three Indonesian satellites operated by National Research and Innovation Agency of Indonesia (BRIN) named LAPAN-A1/TUBSAT, LAPAN-A2/ORARI, and LAPAN-A3/IPB (Triharjanto, 2012). In order to monitor the position of these satellites, ground stations are needed. The new radio telescopes are expected to support the existing ground station to monitor the satellite trajectory.

There are various reason for tracking the AES, such as for maintaining the AES orbital catalog, improving the communication between the ground station and AES, and increasing the quality of AES observation result (Bester, 1996). The calculation of orbital dynamics are an essential part on the AES tracking. The estimation of AES orbits is crucial in order to maintain the AES in its track and determine the satellite maneuvers if necessary. Moreover, as the number of satellites are exponentially growing, a precise calculation is needed in order to avoid a collision with other satellites or debris.

Tracking the satellites can be supported by creating a simulation that give the information about the satellite orbital parameters in real time or even doing a prediction. Here we developed an interactive and web-based AES simulation software named AESSIMS (Artificial Earth Satellite Simulation Software). This software can be used to support the Indonesian radio telescope engineers for tracking the AES. In Section 2, we explain about the design of our web-based software and the development process of this software. The results of satellite tracking simulation by considering Indonesian radio telescopes is given in Section 3. Finally, the conclusion is given in Section 4.

## 2. SOFTWARE DEVELOPMENT

In this AES simulation software, we are creating web-based software with two different programming languages: Python as the back end and JavaScript as the front end. The back end (server-side) is responsible for ensuring the front end (client-side) works. The back end is developed using Django, an open-source high-level Python web framework. The position of Earth satellites and stations (either radio telescopes or ground stations) are modeled using Skyfield (Rhodes, 2019). Moreover, Skyfield is utilized to determine the access time of stations to the AES. The AES position can be predicted by the orbital element information provided by NORAD in Two Line Element (TLE). The elements in TLE are based on the mean value derived from a particular model and needed to fit several observations. Here ”mean” means the periodic components of the orbital evolution is removed. In order to reconstruct the orbital evolution of AES, a similar algorithm has to be implied for reconsidering the periodic terms. Here we adopted the SGP4 orbital model (Hoots and Roehrich, 1980). This model was created based on the analytical theory of Lane and Cranford (1969) which models the atmosphere by a power density function and imply a

*Table 1*

CZML properties to visualize orbit of satellites

| Property Name | Type | Description |
|---|---|---|
| id | String | An ID of an object (Stations or Satellites) |
| name | String | The name that given to object (Station and Satellites) |
| availbility | String | A String of Time Range in Iso 8601 format that determines when an object will appear in the simulation |
| billboard | Object | A billboard is sometimes called a marker, this property will draw viewport-aligned "image" that positioned in the scene by the "position" property. |
| label | Object | A Label will display String of Text that given and place it aside of billboard. "fillColor" and "outlineColor" can be defined here to set the color of the Text |
| path | Object | A path, which is a "polyline" defined by the motion of an object over time. The possible vertices of the path are specified by the "position" property. The path is limited by using the "leadTime" and "trailTime" properties. |
| position | Object | Defines a position of an object according to "cartesian" or "cartographicDegrees" properties. The position can optionally vary over time. |
| polyline | Object | A polyline, which is a line in the scene composed of multiple segments, "color" can be defined here to set the color of the polyline |
| cartesian | Array of Double | Specified position properties in three-dimensional Cartesian value, [X, Y, Z], in meters relative to the referenceFrame, If the position are vary, then array value define as [Time, X, Y, Z] |
| cartographicDegrees | Array of Double | Specified position properties in Cartographic WGS84 coordinates, [Lon, Lat, Alt], where Longitude and Latitude are in degrees and Alt is in meters. If the position are vary, then array value define as [Time, Lon, Lat, Alt] |
| image | Uri | Uri of an image that will be displayed at "billboard" |
| interpolationAlgorithm | String | The interpolation algorithm to use when interpolating. We used Lagrange polynomial interpolation. |
| interpolationDegree | Double | The degree of interpolation to use when interpolating. |
| referenceFrame | String | The reference frame in which "cartesian" "positions" are specified. Here we used Intertial reference frame. |
| epoch | String | The epoch to use for times specified as seconds since an epoch. |
| leadTime | Double | The time ahead of the animation time, in seconds, to show the "path". |
| trailTime | Double | The time behind the animation time, in seconds, to show the "path". |
| color | rgba | Defines color of an object that given in [r, g, b, a] Format |
| fillColor | rgba | Defines fill color of an object that given in [r, g, b, a] Format |
| outlineColor | rgba | Defines the outline color of an object that given in [r, g, b, a] Format |

solution of Brouwer (1959) for the gravitational model.

Skyfield library gives the information such as the satellite position, time of Acquisition of Signal (AOS), and time of the Loss of Signal (LOS). This information are predicted from TLE through SGP4 perturbation model by initiating Class EarthSatellite($E_1, E_2, E_0, t_a$)=E where $E_1$, $E_2$, $E_0$ are line 1, 2, and satellite name in the TLE respectively. Here $t_a$ means the starting time of the prediction. For the sake of visualization, we convert the satellite orbital elements from TLE into Cartesian coordinate ($XYZ$) relative to the Earth center. This can be done by using the function E.at(t). The time of AOS and LOS can be retrieved by using the function E.find_event($\lambda, \phi, t_a, t_b, h$), where $\lambda$ is longitude, $\phi$ is latitude, and $h$ means the altitude.

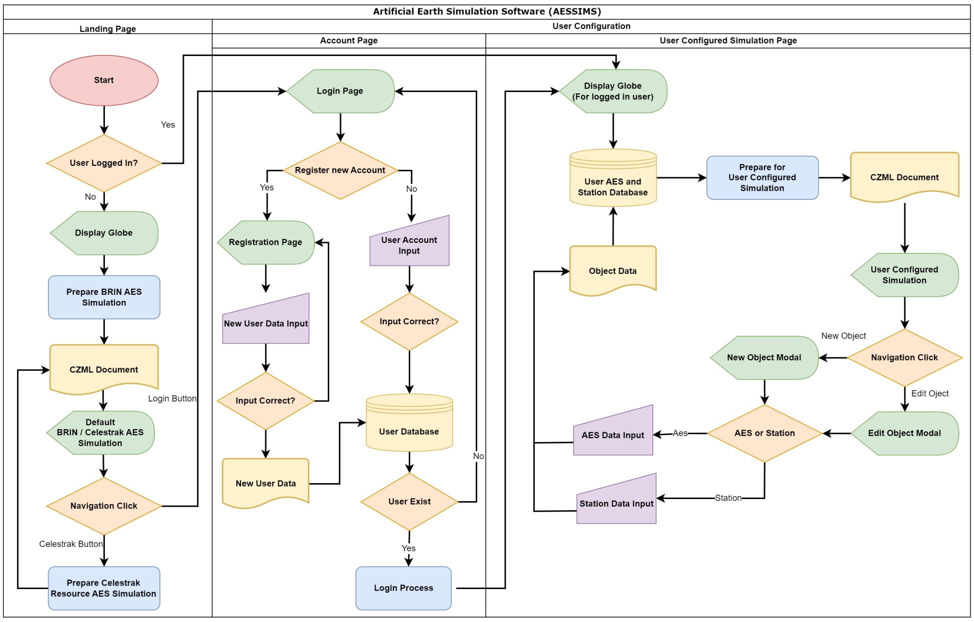



Fig. 1 – Flowchart of AES simulation software.

The front end is developed using an open-source 3D globes and maps JavaScript library called CesiumJS. This library can visualize data provided in Cesium Language (CZML). It is based on JavaScript Object Notation (JSON) data-interchange text format. The output from Skyfield library is transformed into CZML format and displayed by the CesiumJs library as a user interface. As shown in Table 1, several properties are needed to visualize the AES trajectory and the ground station in CZML. CZML is a format based on JSON that is used to describe graphical scenes that change over time, primarily for display in Cesium, a web browser. It defines various graphical elements, such as lines, points, models, and billboards, and specifies how they evolve over time. In AESSIMS, Station and Satellite objects are created using billboard and polyline properties, respectively. These objects are then stored in an array and sent back to the AESSIMS frontend to be displayed in the Cesium library. Each object in CZML requires an ”id” and ”availability” property, which are mandatory. Cesium uses the ”id” to identify each object, while ”availability” defines the time range during which the object is available. Additionally, objects can be named using the ”name” property. When an object is clicked, its name and description are displayed in the frontend.

AESSIMS can be accessed through the website https://satelitku.brin.go.id/. As shown in Figure 1, the flowchart is divided into three sections, the landing page and the user-configured page which consist of the login page and user-configured simulation page. By default, the landing page shows the visualization of the Indonesian AES trajectory with four Indonesian ground stations and a ground station in Spitsbergen. On the landing page, users also can visualize over 180 AES trajectories based on https://celestrak.org/NORAD/elements/resource.txt TLE by clicking the “Celestrak Satellites” button. Additionally, users can create a new account or login into their existing account to configure their simulation at the login page.

At the user-configured simulation page, the user can add another station, such as a radio telescope, or even another satellite by manually inputting the station name and position data and the satellite TLE URL or inputting the elements. All the data will be stored in the SQLite database so the users can view their configuration each time they login.

As seen in Figure 2, there are several menus in this software. The detail of each menu in the *left-hand side* figure is given as follows:

a: Home button (the default position of the globe),

b: Scene mode picker (changing screen mode into 3D / 2.5D / 2D),

c: Login/Logout Button,

d: Help button,

e: Control,

f: Timeline,

g: Fullscreen button.

The detail of *right hand side* figure of Figure 2 is:

a: Realtime Button (changing time into current time), b: Ring Pointer (controlling the speed of simulation whether it is for reverse or forward simulation),

c: Ring Path (speed indicator which is already set by the ring pointer),

d: Timeline button (setting the satellite position based on a specific time),

e: Current speed information,

f: Current date information,

g: Current time information,

h: Play reverse simulation,

i: Play/Pause button (resume or pause the simulation),

j: Play forward simulation.

We can add the timeline of the AES trajectory in the software. Here the user can interactively change the time by dragging the blue triangle bottom in the timeline bar (timeline button). The time chosen by the user is shown in the bottom left. Furthermore, we can pause the movement by clicking the pause symbol. We can also choose the type of movement of the AES, either forward or backward simulation.

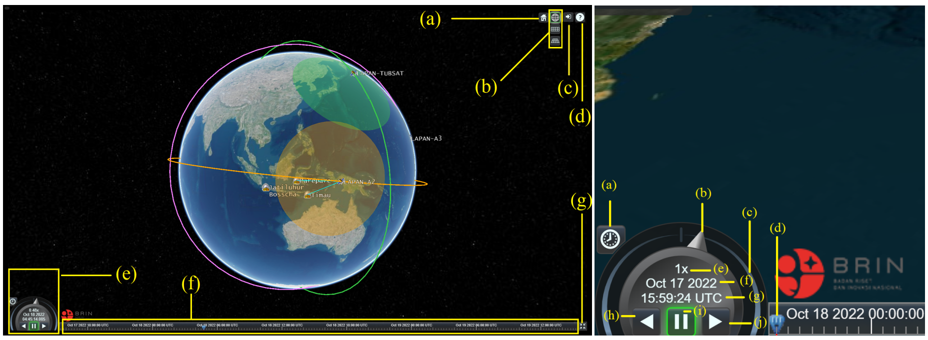



Fig. 2 – Several menus that are available in the software. *Left*: menus in full screen mode; *right*: menus in timeline part. Detail of each menu is given in the text.

### 3. SIMULATING SATELLITE TRACKING BY INDONESIAN RADIO TELESCOPES

In this work, we used AESSIMS software to simulate the tracking of satellites by Indonesian radio telescopes. We simulated three AES of BRIN, called LAPAN-

*Table 2*

Future radio telescopes that are considered in the simulation. EOP is Earth Orientation Parameters and TRF/CRF mean Terrestrial/Celestial Reference Frame

| Name | Lat,Lon | Altitude (meter) | Diameter (meter) | Scope of Observation |
|---|---|---|---|---|
| Jatiluhur | $-6.522°$, $107.411°$ | 131 | 18.3 | EOP, TRF, CRF |
| Bosscha | $-6.824°$, $107.617°$ | 1280 | 13 | EOP, TRF, CRF |
| Parepare | $-3.978°$, $119.650°$ | 75 | 11 | EOP, TRF, CRF |
| Timau | $-9.597°$, $123.947°$ | 1313 | 20 | Maser, Galaxies, Solar System |

A1/ TUBSAT, LAPAN-A2/ORARI, and LAPAN-A3/IPB. Four future Indonesian radio telescopes are considered in the simulation. Table 2 shows a brief explanation of each telescope. All telescopes will be used to track the satellites in their idle time.

Each satellite has to be provided with an id, name, and availability. Object id is essential since it is used as a reference for the access between the radio telescopes and the satellites. For the radio telescopes, we need to provide information such as longitude, latitude, and altitude. The Skyfiled library is used to calculate the cartesian coordinate of AES from TLE. It is necessary to calculate the AOS and LOS of the AES to determine the access between AES and the radio telescopes.

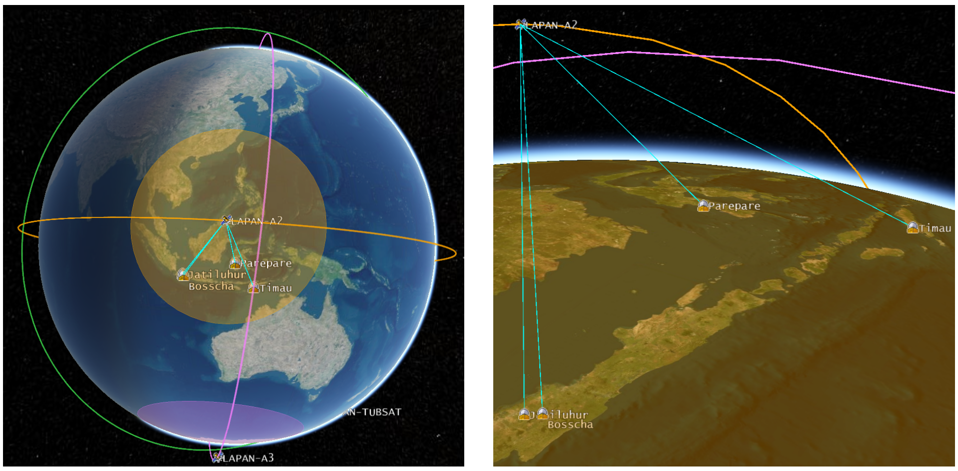
Figure 3 shows the visualization of AES trajectory and radio telescopes position. The orange circle represents a field of view of satellite LAPAN-A2. Here the trajectory of each AES has a different color for better visualization. Figure 3 shows a zoom version. In this example, the AES named LAPAN-A2 is located above Indonesia. When the AES is on the horizon of the radio telescope, a blue line appears and connects the AES to the radio telescope. This line automatically disappears when the AES reaches the LOS time. Table 3 shows the example of the AOS and LOS timetable for one day. The mentioned timetable can play a crucial role in planning for radio telescope observations that are scheduled in the near future. The schedule is particularly useful in two scenarios. Firstly, it can assist in mitigating the potential interference caused by satellite signals, which can have an adverse impact on the accuracy of radio telescope observations. Secondly, the timetable can be used for observing the satellite itself, allowing researchers to study and analyze data from the satellite signal.

To confirm the accuracy of our findings, we compared them with those of other software, specifically the Systems Tool Kit (STK) from Ansys Government Initiatives (https://www.ansys.com/products/missions/ansys-stk), which is a widely recognized software for simulating the AES's orbital motion. In Figure 4, the time differences between the AOS and LOS obtained from two different software are displayed. Here we compare the simulation results of the satellite tracking by a radio

*Table 3*

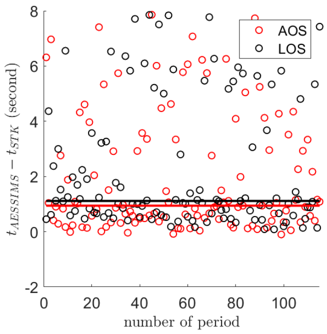
AOS and LOS of each satellite during 16th October 2022. The time (hour:minute:second) is in UTC

| Satellite | Radio Telescope | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Jatiluhur | | Bosscha | | Parepare | | Timau | |
| | AOS | LOS | AOS | LOS | AOS | LOS | AOS | LOS |
| LAPAN-A1 | 07:06:13 | 07:17:40 | 07:06:06 | 07:17:36 | 05:34:13 | 05:38:00 | 05:30:32 | 05:38:03 |
| | 08:42:00 | 08:53:38 | 08:41:56 | 08:53:31 | 07:05:27 | 07:18:32 | 07:03:48 | 07:16:47 |
| | 19:17:59 | 19:30:20 | 19:18:02 | 19:30:25 | 08:46:11 | 08:49:10 | 17:42:58 | 17:53:34 |
| | 20:55:13 | 21:04:56 | 20:55:21 | 21:04:57 | 17:43:11 | 17:50:56 | 19:18:06 | 19:30:06 |
| | - | - | - | - | 19:16:27 | 19:29:13 | - | - |
| LAPAN-A2 | 00:17:31 | 00:29:48 | 00:17:31 | 00:29:48 | 00:20:32 | 00:33:46 | 00:22:42 | 00:34:20 |
| | 02:01:50 | 02:14:36 | 02:01:50 | 02:14:36 | 02:04:49 | 02:18:29 | 02:06:50 | 02:19:18 |
| | 03:45:59 | 03:59:24 | 03:45:59 | 03:59:24 | 03:49:03 | 04:03:07 | 03:50:53 | 04:04:08 |
| | 05:30:08 | 05:44:05 | 05:30:08 | 05:44:05 | 05:33:21 | 05:47:39 | 05:34:59 | 05:48:48 |
| | 07:14:23 | 07:28:38 | 07:14:23 | 07:28:38 | 07:17:43 | 07:32:06 | 07:19:11 | 07:33:19 |
| | 08:58:42 | 09:13:05 | 08:58:42 | 09:13:05 | 09:02:09 | 09:16:32 | 09:03:30 | 09:17:44 |
| | 10:43:06 | 10:57:30 | 10:43:06 | 10:57:30 | 10:46:37 | 11:00:58 | 10:47:53 | 11:02:06 |
| | 12:27:33 | 12:41:54 | 12:27:33 | 12:41:54 | 12:31:04 | 12:45:25 | 12:32:19 | 12:46:23 |
| | 14:11:59 | 14:26:12 | 14:11:59 | 14:26:12 | 14:15:31 | 14:29:48 | 14:16:53 | 14:30:32 |
| | 15:56:32 | 16:10:27 | 15:56:32 | 16:10:27 | 16:00:01 | 16:14:04 | 16:01:36 | 16:14:37 |
| | 17:41:12 | 17:54:37 | 17:41:12 | 17:54:37 | 17:44:38 | 17:58:18 | 17:46:29 | 17:58:40 |
| | 19:25:59 | 19:38:47 | 19:25:59 | 19:38:47 | 19:29:21 | 19:42:35 | 19:31:25 | 19:42:50 |
| | 21:10:47 | 21:23:04 | 21:10:47 | 21:23:04 | 21:14:00 | 21:27:00 | 21:16:14 | 21:27:17 |
| | 22:55:26 | 23:07:37 | 22:55:26 | 23:07:37 | 22:58:32 | 23:11:35 | 23:00:45 | 23:12:02 |
| LAPAN-A3 | 01:18:22 | 01:27:57 | 01:18:29 | 01:28:01 | 11:31:12 | 11:42:39 | 11:29:30 | 11:41:04 |
| | 11:32:38 | 11:41:05 | 11:32:33 | 11:41:02 | 13:08:03 | 13:12:45 | 21:55:36 | 21:59:10 |
| | 13:05:02 | 13:15:54 | 13:04:58 | 13:15:49 | 23:23:50 | 23:35:12 | 23:24:59 | 23:36:31 |
| | 23:26:41 | 23:35:08 | 23:26:38 | 23:35:15 | - | - | - | - |

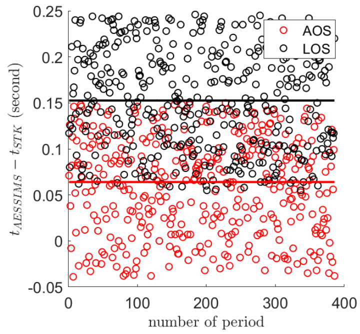



(a) (b)

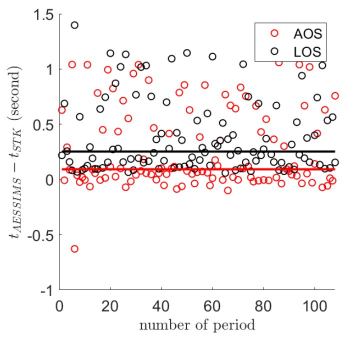
Fig. 3 – Visualization of AES position and trajectory as well as the position of radio telescopes in normal (a) and zoom version (b).




(a)




(b)




(c)

Fig. 4 – Time difference of AOS and LOS between AESSIMS ($t_{AESSIMS}$) and STK ($t_{STK}$) with epoch in February 2, 2023 for all Indonesian satellites. Red and black lines represent the median value of AOS and LOS time difference respectively. Here we consider the radio telescope in Parepare as an AES signal receiver.

telescope located in Parepare. The results show that the median time difference for all Indonesian satellites is less than one second. However, the time difference is relatively greater for LAPAN-A1/TUBSAT. It should be noted that differences in various versions of SGP4 could be the source of this variation. Moreover, here we did not take into account other factors that could influence the simulation's outcome, such as solar radiation pressure. Despite this, the difference is not significant because there is typically a minimum delay of 5 seconds before the satellite can communicate with the receiver. These results suggest that the simulation is reliable, and the time difference is acceptable.

## 4. CONCLUSION

Indonesia has recently announced its intention to build new radio telescopes at multiple locations. These telescopes are primarily designed for astronomical observations, but they can also be used to detect AES, either as an individual disk or as part of a network. Our research is focused on exploring the potential of these telescopes for tracking AES. Here we have developed a web-based simulation software called AESSIMS that allows interactive modeling of the AES's orbital dynamics. We built this software based on Django and Skyfield as a back end and CesiumJS for its front end. This software can be used to track the AES in real-time, predict the position of AES in the future, or to see its position in the past. The orbital dynamics of AES is depicted through three or two dimension visualization. In this study, we examined the use of this software by simulating the satellite tracking by Indonesian radio telescopes. We found that the results of this software match the results of existing software. This software can be used to help the technician for tracking the satellite from each Indonesian radio telescope.

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*Author contribution.* Conceptualization: SYB, INH, SR, MBS, TH; Software: SYB; Writing orignial draft: SYB, INH; Visualization: SYB, INH; Review and editing: SYB, INH, RWW, ML, FM, PS, MB, TM, TH, SR; Funding acquisition: SYB, INH, SR, MBS, FM, RWW, TH. All authors have read and agreed to the published version of the manuscript.

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