Estimation of Accessible Probability in a Low Earth Orbit Satellite to Ground Laser Communications

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Abstract. *The accessible probability of a low-orbit satellite from ground is estimated by using images taken by a meteorological satellite and by analyzing visible passes of the satellite. The study indicates that the blockage by clouds in satellite-ground laser communications is almost avoidable by properly distributing several optical ground stations. For the calculation, we use an orbit information of a low-earth orbit satellite, the Optical Inter-orbit Communications Engineering Test Satellite (OICETS), as the counterpart of the optical ground stations. The calculation of the cumulative accessible probability shows the required time to achieve over 99% accessibility between the low orbit satellite and the optical ground stations.*

Keywords

Satellite-ground laser communications, optical ground stations, low earth orbit, OICETS.

1. Introduction

The reports on successful demonstrations of inter-satellite and satellite-ground laser communications attract attentions for the future applications. A geostationary satellite of European Space Agency (ESA), the Advanced Relay Technology Mission Satellite (ARTEMIS), and a low earth orbit satellite of Japan Aerospace Exploration Agency (JAXA), the Optical Inter-orbit Communications Engineering Test Satellite (OICETS), conducted cooperative inter-orbit laser communications repeatedly in 2005 and 2006 [1]. The OICETS-ground laser communication experiments were performed in 2006 with the optical ground station (OGS) of the National Institute of Information and Communications Technology (NICT) in Tokyo Japan and with the transportable OGS of the German Aerospace Center (DLR) located in Oberpfaffenhofen, Germany at that time, respectively [2], [3]. In 2008, the coherent laser communications were demonstrated with the data rate of 5.6 Gbps between a German satellite TerraSAR-X and a US satellite NFIRE [4]. TerraSAR-X successfully performed the satellite-ground laser transmission demonstrations [5]. Those inter-orbit experiments achieved stable bidirectional data transmission and the satellite-ground trials indicated the potential of the use of optical links going through the atmosphere.

In 2008, OICETS-ground experiments were conducted again with NICT's OGS. In 2009, the experiments were expanded in cooperation with four OGSs of DLR, ESA, Jet Propulsion Laboratory (JPL), and NICT, respectively [6], [7]. Due to the restrictions on the OICETS operation, the trial periods for those stations were separately scheduled. But the effectiveness of combination of plural optical ground stations was clearly observed because experiments were successfully conducted at one of the sites even when another location is covered with thick clouds.

When the high data rate transmission is required in satellite-ground links, the free-space laser communications would be one of the promising candidates. However, it is always necessary to consider how to avoid the blockage by clouds. One of the solutions is the use of multiple OGSs placed in different sites. This approach is effective since the distribution of clouds changes spatially and temporally. Besides, an additional issue to be considered is the number of accesses to a satellite from ground stations if the satellite is non-geostationary orbit.

In this work, we study the availability of the satellite-ground laser communications from a view point of the accessible probability. First we estimate a probability to avoid the blockage by clouds with assuming a combination of several OGSs. In the calculation, the images taken by Japanese meteorological satellite (MTSAT) are used. Therefore, the computed results are related to the Japanese region. However, it provides a significant insight of the use of multiple locations. Next we analyze the visible pass predictions of OICETS from the locations of the optical ground stations that were used for the satellite-ground experiments carried out in 2009. The analysis indicates the continual connections between a non-geostationary satellite and ground stations.

2. Probability to Avoid Blockages by Clouds

For the estimation of the probability to avoid the blockage by clouds, we assume 8 sites to allocate OGSs in Japan area as shown in Fig. 1 for example. The images used for analysis were provided by MTSAT. Fig. 2 is a sample image on June 1st, 2007. The detection wavelength ranges between 10.3 µm and 11.3 µm. The original images are 12-bit grayscale and taken by every 30 minutes with the pixels of 2750-by-2750 covering the field-of-view of the satellite. For our study, the images between June 1 2007 and May 31 2008 are used. Each image is processed to extract the pixel values corresponding to the selected sites. Although the atmospheric characteristics such as the transparency are beyond the considerations due to this approach based on the pixel values of the images, the evaluation contributes to observe the combination effect of the multiple ground locations.

Tab. 1 shows the sets of locations for calculation where the labels of the case A to the case F include the locations notated with circles, respectively. Fig. 3 shows the monthly averaged probability to avoid the blockage by clouds. As a result of the calculation, the period within which at least one of the selected locations remains under the clear sky is obtained. In Fig. 3, the minimum value of the monthly averaged probability in a year is less than 0.4 in the case of the single ground station. The contribution of the set of OGSs to increase the probability is clearly observed. The results are summarized in Tab. 2.

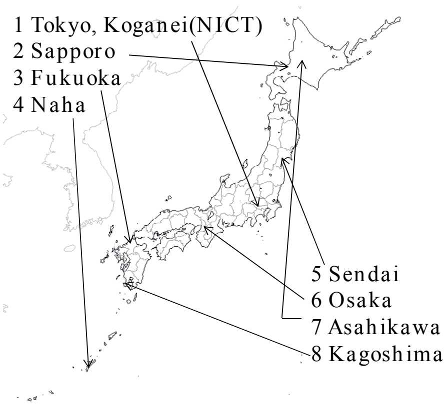

Fig. 1. Selected locations for estimation.

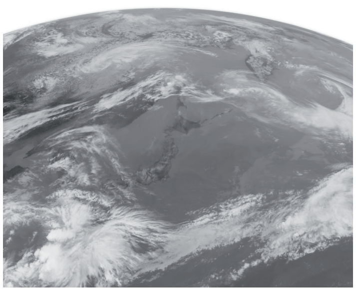

Fig. 2. Sample image used for calculation.

	Case					
Locations	A	B	C	D	E	F
1 Tokyo	○	○	○	○	○	○
2 Sapporo		○	○	○	○	○
3 Fukuoka			○	○	○	○
4 Naha				○	○	○
5 Sendai					○	○
6 Osaka					○	○
7 Asahikawa						○
8 Kagoshima						○

Tab. 1. Set of locations.

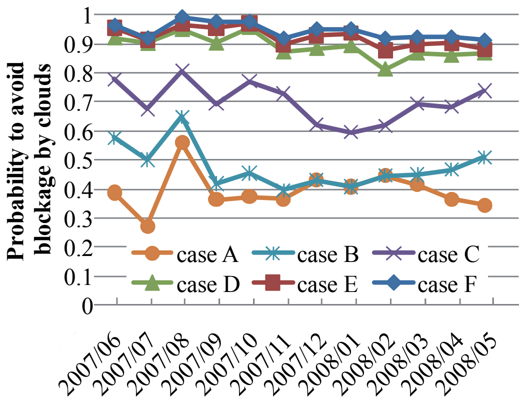

Fig. 3. Monthly averaged probability to avoid blockage by clouds.

case	A	B	C	D	E	F
Ave.	0.39	0.48	0.70	0.89	0.92	0.94
Max.	0.56	0.65	0.81	0.96	0.97	0.99
Min.	0.27	0.40	0.60	0.81	0.88	0.91
Diff.	0.29	0.25	0.21	0.14	0.09	0.08

Tab. 2. Summary of monthly probability.

3. Visible Passes from Ground

If the satellite is in the geostationary orbit, a ground station could stay within the view of the satellite. But in low-earth orbit satellite cases, the accessible chances between the satellite and ground stations are temporally changed.

OICETS was a relatively small satellite with the mass of approximately 570 kg. The orbit was circular at the height of about 610 km and the inclination angle of 97.8 degrees [1]. The locations of the OGSs at which the satellite-ground laser communication demonstrations were performed in 2008 and 2009 are shown in Fig. 4. Fig. 5 shows the visible passes of OICETS from the ground stations on Feb. 1, 2009 for example. The recurrence period of the visible pass patterns is about 11 days. The calculation assumes that the satellite is visible above the 0-deg elevation at ground and the visible passes less than 1 minute are eliminated. According to the figure, we note that the visible passes are distributed almost evenly within 24 hours. Therefore OICETS is continually accessible from one of the four OGSs. However we still find the periods of a few hours denoted by black dotted circles in which no ground stations can look at the satellite. To fill the periods, we need additional OGSs placed in different location.

The use of the multiple OGSs for the satellite-ground laser communications, the coordinated control of the OGSs connecting to terrestrial networks is necessary. Concerning the broadband terrestrial networks, NICT has launched the operation of research and development test bed network named JGN2plus [8]. The network provides Ethernet connectivity by the layer 2 switches and IP connectivity with IPv4/IPv6 dual stack capability on the layer 3. The backbone points are connected with data transmission rate from 1Gbps to 20Gbps and other access points are connected with 100Mbps. To our knowledge, many countries and regions provide their broadband network services as shown in Fig. 6 [8-20], and those networks are mutually connected. In this figure, the bold solid lines indicate the data rate of 10Gbps or more and the thin lines mean less than that. Figs. 4 and 6 suggest that the candidate locations for additional OGSs to fill in the blank periods in Fig. 5 will be Australia or the east part of US. This is because the broadband terrestrial networks are provided in those regions, and those locations are sufficiently separated from other areas, respectively. The visible passes of OICETS are calculated on Boston and Perth for instance and shown in Fig. 7. As expected, the blank periods in Fig. 5 are filled if one of the two locations is added to the four OGSs. This tendency remains the same in other days. Besides, since the weather conditions of those areas could be quite different, the results of the visible passes imply that the combination of those stations could provide a high accessibility even in the LEO satellite-ground laser links.

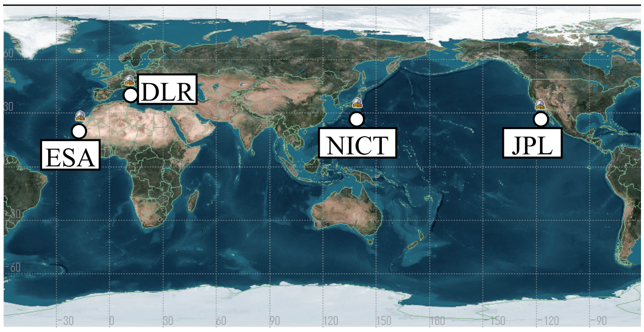

Fig. 4. Locations of OGSs for OICETS-ground laser communication demonstrations performed in 2008 and 2009.

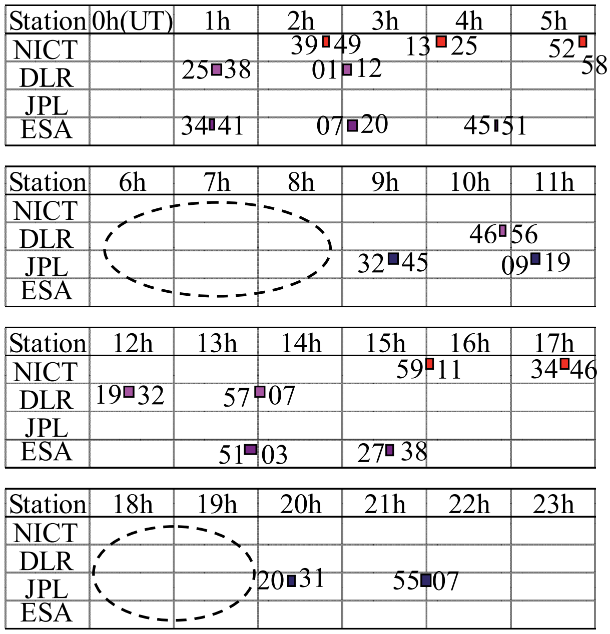

Fig. 5. Visible passes of OICETS from the OGSs on Feb. 1, 2009.

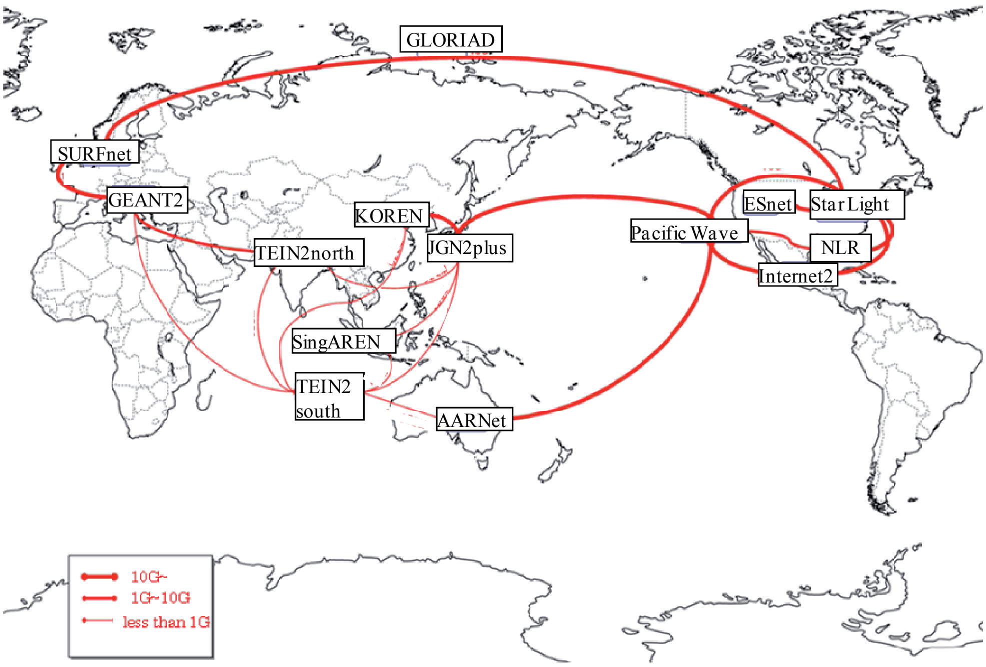

Fig. 6. Broadband terrestrial networks.

One of the important properties on the satellite-ground connections is the cumulative access probability as a function of time. When the probability of the avoidance of the cloud blockage at the i-th location is given as p_i, the combination of N-locations provides the total probability P as $P = 1 - \prod_{i=1}^{N} (1 - p_i)$ on condition of no correlations in the cloud distribution on those areas. According to the number of the visible passes per an hour according to Fig. 5 and Fig. 7, the cumulative access probabilities P_{CAP} are calculated as a function of time. For computation, we assume for simplicity that all these 6 sites have the equivalent probability of the cloud blockage avoidance given as p_{av}. The computed results of P_{CAP} are shown in Fig. 8, where the abscissa is the elapsed time counted from 0h (UT). Fig. 9 is the cumulated-blockage probability P_{CBP} given by P_{CBP} =1- P_{CAP}. If we look at the case that the probability of the cloud blockage avoidance is given as p_{av}= 0.5, the accessible probability exceeds 99% after 5 hours. Similarly, the time to exceed 99% accessibility is 4 hours for p_{av}= 0.7. We note that even if the case of p_{av}= 0.3, the accessibility exceeds 99% after 8 hours, though the achievable maximum accessibility is 0.96 for the case of p_{av}= 0.1 after 24 hours.

Station	0h(UT)	1h	2h	3h	4h	5h
BTN						
PRT						32□44

Station	6h	7h	8h	9h	10h	11h
BTN	17■29	53■04				
PRT	07□19					

Station	12h	13h	14h	15h	16h	17h
BTN					09■20	
PRT					19□29	53□

Station	18h	19h	20h	21h	22h	23h
BTN	44■56					
PRT	□05	34□37				

Fig. 7. Visible passes of OICETS from the OGSs on Feb. 1, 2009.

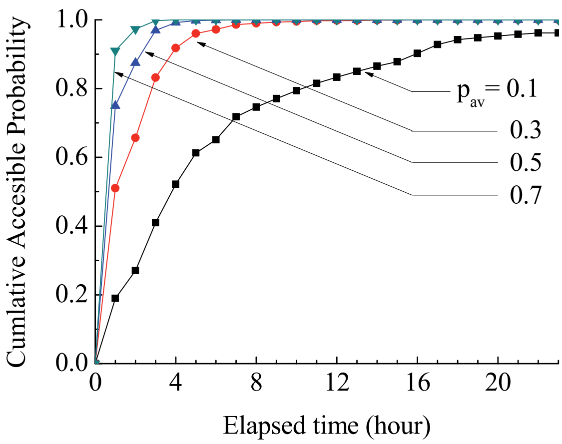

Fig. 8. Cumulative accessible probability

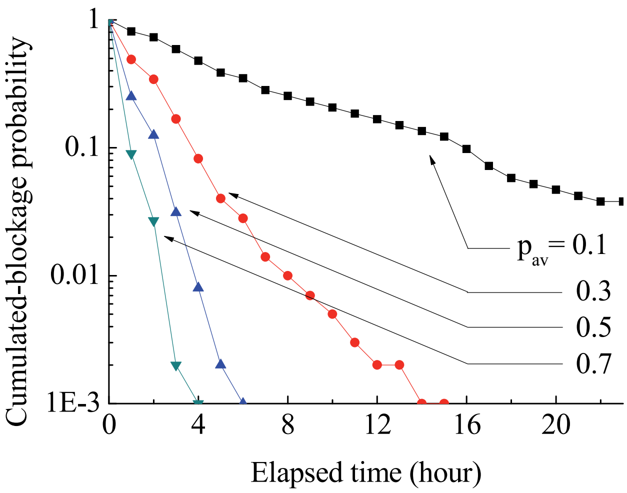

Fig. 9. Cumulated-blockage probability.

4. Conclusions

The availability of the satellite-ground laser communications has been studied. First the probability to avoid the blockage by clouds has been estimated with using images taken by a meteorological satellite. Next the visible pass predictions of the satellite have been analyzed at the locations of the optical ground stations. The cumulative probability of the cloud blockage avoidance as a function of time has indicated that the continual connections even between a non-geostationary satellite and ground stations are possible. The sample calculation of the cumulative accessible probability has shown the required time to achieve over 99% accessibility.

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Nobuhiro KURA joined SPACE ENGINEERING DEVELOPMENT Co., Ltd. (SED) in 1990. He developed ground systems for satellites such as ETS-VI, ADEOS, etc. He moved to National Space Development Agency of Japan (NASDA) between 2001 and 2002, and developed ground systems for OICETS experiment. He moved to Japan Aerospace Exploration Agency (JAXA), formally NASDA, in 2004 again to conduct laser communication demonstrations with OICETS and back to SED in 2007.