An Efficient Utilization of Intermittent Satellite-to-Ground Links by Using Mass Storage Device Embedded in Satellites

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An Efficient Utilization of Intermittent Satellite-to-Ground Links by Using Mass Storage Device Embedded in Satellites

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***Abstract*—In recent years, tremendous amount of traffic is delivered by the Internet. However, ground networks cannot provide communication environment to disaster areas and isolated areas such as mountain and sea. Thus, as the next generation networks, optical satellite networks have attracted much attention because of many advantages such as high capacity, disaster resistance, and large coverage. Since optical communication can increase traffic rate in comparison with radio wave, the optical satellite networks can provide high speed communication. On the other hand, optical communication is greatly influenced by the atmospheric condition, which can lead to traffic congestion. Thus, we focus on utilizing satellites with embedded mass storage device to manage large amount of traffic in the network. Since satellites embedded mass storage device can store the traffic temporary, it is possible to deliver the data when the downlink condition is more favorable. However, there are no traffic control method that effectively use mass storage device embedded in satellite while taking into account optical link between satellite and optical ground station. Therefore, in this article, we propose a new traffic control method to effectively use mass storage device embedded in satellite according to optical downlink condition between satellite and optical ground station.**

I. Introduction

Recently, wireless communication devices, such as smartphones and tablet computers are gaining popularity because these devices make it possible to easily access the Internet at anytime and anywhere. As a result, the amount of Internet traffic generated from all over the world becomes enormous. However, since the network infrastructures which provide Internet service consist of ground-based station, the networks are often failed or restricted due to the failure of the infrastructures as demonstrated during the event of disaster. Moreover, it is difficult to deploy the network in the many isolated areas, such as seas or mountain because the infrastructure cannot be constructed in those areas. Therefore, satellite networks have attracted much attention as the next generation network due to their disaster resistance and large coverage properties. The satellite networks which consist of satellite orbiting around the earth are not influenced by disasters, such as earthquakes and floods. In addition, satellite can cover a very large area due to its high altitude. By constructing a constellation of satellites, the satellite network can extend its coverage to cover all over the world. On the other hand, space utilization researches, such as Earth observation and planet exploration require high quality contents such as high definition video data and high resolution observation data. Thus, the satellite network needs to transmit large amount of data generated from both ground and space. In Japan, National Institute of Information and Communications Technology (NICT) has developed the rapid data transmission satellite, namely Wideband Inter-Networking engineering test and Demonstration Satellite (WINDS) with Japan Aerospace eXploration Agency (JAXA) and have succeeded in conducting communication experiment in space [1]. Although rapid data transmission satellite like WINDS only adopt a specific radio wave, which is named Ka band to communicate, utilization of laser light which achieves high-speed communication also attracts attention. In comparison with radio wave, laser light has short wavelength, which make it possible to generate directional beam with small antenna. In this way, optical satellite communication has great advantages. However, they have a highly important feature that they are easily influenced by weather condition because light refract from different refractive index profile in atmosphere. Therefore, in optical satellite-to-ground communications, link capacity among satellite and ground is drastically affected by the time that the laser is subjected to weather condition. Thus, satellite network which each satellite has an optical downlink between itself and the ground cannot deliver a lot of traffic under bad weather condition. In such situation, traffic congestion often occurs at the satellites due to the limited downlink capacity because it is required to send a lot of data generated from both ground and space. Therefore, in this research, we focus on utilizing embedded mass storage device on satellite. Embedded mass storage device on satellite enables the satellite to store and send the data at a later time when the weather and the downlink condition are more favorable [2], [3]. One of many examples of a satellite equipped with mass storage device is the Advanced Land Observing Satellite (ALOS), which was launched in 2006 by JAXA. ALOS is an earth observation satellite and has embedded mass storage device with capacity of 96GB [4]. There are many research works on Delay and Disruption Tolerant Network (DTN) that are related to satellite with mass storage devices due to similarity in using the store-and-forward approach to send message from source to destination with intermittent link [5]. However, in the past, there have not been any researches that consider embedded mass storage device in the optical satellite networks. Thus, we propose a new traffic control method, which utilize the mass storage devices embedded on the satellites in order to manage high amount of data in the optical satellite networks. The assumed satellite constellation is presented in Section II. In addition, the existing researches for optical communication are introduced in this section. Furthermore, we show the simple usage of mass storage device and their shortcoming. Section III describes our proposed method to effectively utilize mass storage device embedded in satellite. Section IV contains an evaluation of the transmission time in our proposed method. Finally, concluding remarks are provided in Section V.

II. Satellite Networks with Mass Storage Devices and Optical Communication Technologies

In this section, firstly, we introduce a satellite network consisting of satellites constellation and traffic control method employed in the networks. Secondly, we describe optical communication technologies for satellite communications. Finally, we discuss the possible usages of mass storage device to improve the performance of the network.

A. General satellite networks

Satellites are generally classified into three types according to their altitude. Low Earth Orbit satellite (LEO) has the lowest orbit and Medium Earth Orbit satellite (MEO) is the second lowest one while Geostationary Earth Orbit satellite (GEO) has the highest orbit. GEO satellites have an altitude of 36,000 km, and thus have extensive coverage area that can cover the earth entirely when only three satellites are used. One important feature of GEO satellites is that they always cover the same region of the earth, because of its fixed position against the earth's surface. On the other hand, LEO satellites can extend their coverage to cover the whole earth by constructing constellation [6]. Since the altitude of LEO satellites is only about 350 km to 1,400 km, they can observe the earth in detail. Iridium is a famous LEO satellites network constructed by 66 satellites, and is used to provide worldwide telephone and data delivery service. It has a mesh topology, which is constructed by 6 orbits and 4 Inter Satellite Links (ISLs). The constellation of satellites is also used for the earth observation. In LEO satellite networks, data is sent from ground station or generated in a satellite and transmitted among several satellites. After the traffic reaches the satellite which can communicate with the destined ground station, the satellite sends the traffic to ground station. For satellite networks, it is important to select suitable paths to deliver the traffic. Each satellite in satellite networks has the same ability to process data. Thus, all ISLs should be equally utilized in the satellite networks to achieve efficient network utilization. For these reasons, routing strategy is one of the most important issues in satellite networks. Today, many routing methods are proposed and many of them are based on the Dijkstra's Shortest Path (DSP) algorithm . In DSP, the path with minimum link cost is chosen, where link cost is the barometer representing transmission delay or hop count and so on. DSP is the simplest routing method, hence many networks employ DSP. Satellite networks that employ DSP can deliver traffic with shortest path, traffic may concentrate the particular satellite and congestion will occur. In order to prevent satellite networks from being congested, Explicit Load Balancing (ELB) is proposed . In ELB, each satellite checks their buffer and when traffic concentrate and increase the risk of the congestion, the satellite then informs their condition to adjacent satellites. Adjacent satellites received the messages and detour the traffic to other satellites. As a result, the traffic rate to the satellite, which congestion is expected decrease and congestion can be avoided. Although ELB can avoid congestion at the relay satellite, it cannot avoid congestion at the satellite which covers the destined ground station. It is because, when congestion occurs at the satellite that covers the destination, traffic cannot be detoured to another satellite. Congestion at satellite networks leads to packet drop. Thus, it is required to avoid the congestion while transmitting to the ground station.

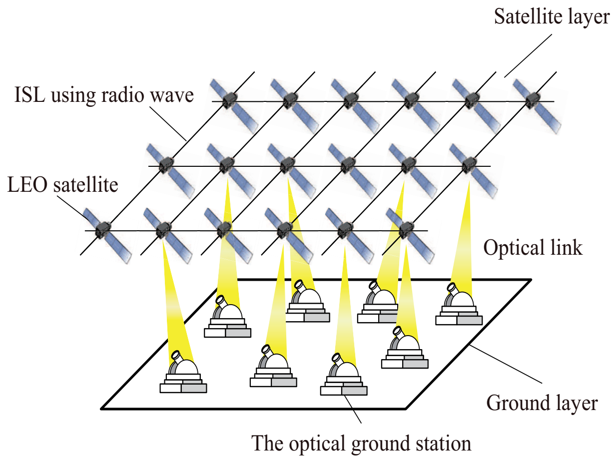


Fig. 1. An example of optical satellite networks.

B. Optical link between satellite and optical ground station

As previously mentioned, optical communication technology for satellites has been researched all over the world. European Space Agency (ESA) has already succeeded in many optical communication experiments [7]. They developed Advanced Relay and Technology Mission (ARTEMIS) which is the GEO satellite for satellites optical communication experiment. ARTEMIS has communicated with airplane using optical link and has also communicated with optical ground station. NICT accomplished the world's first optical communication experiment between the GEO satellite of ETS-VI and a optical ground station [8]. In addition, NICT conducted various experiments in cooperation with other institutes, and successfully establish optical link fifteen times out of twenty seven times. Taking into consideration of current satellite optical communication experiments, many experiments that construct optical link between satellite and ground are conducted. Therefore, in this paper, we assume a satellite network where each satellite has an optical link between itself and the ground. Since it is difficult to concurrently establish and maintain optical links for both satellite-satellite and satellite-ground connection, the links between each satellite are made up of radio wave as illustrated as Fig. 1. In addition, we assume satellite-to-ground optical link capacity is around 0.5Gbps.

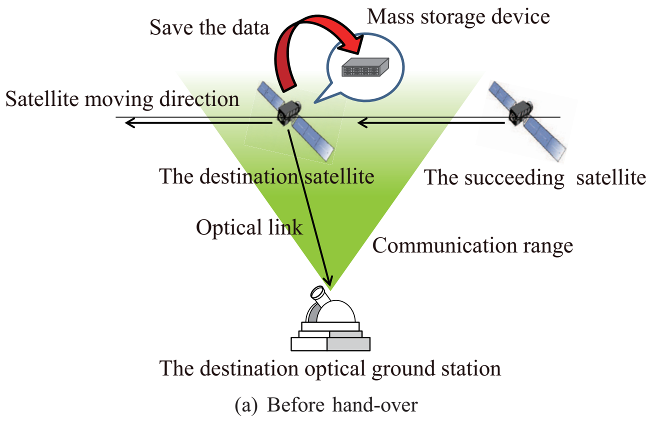


Fig. 2. Usage of mass storage device.

C. Different usages of mass storage device embedded in satellite

In this subsection, we consider the effectively usage of mass storage device embedded in satellite take into account optical downlink condition.

1) Two simple usages of mass storage device: We illustrate the usage of mass storage device with a specific scenario where a large volume of traffic is sent to a single optical ground station. It is obvious that there will be some congestion at the satellite which currently has connectivity to the destined optical ground station. We will be referring to this satellite as the destination satellite for the rest of the paper. Generally, the simplest way to use mass storage device is to have the destination satellite buffer the data which cannot be delivered to the destination due to unfavorable optical downlink condition, and deliver those buffered data when optical downlink condition improves as shown in Fig. 2(a). However, as LEO satellites orbit around the earth, a certain LEO satellite may be communicating with a optical ground station at some moment but it may soon move out of the communication range of the optical ground station as shown in Fig. 2(b). When this occurs, the destined optical ground station switches from communicating with the current destination satellite to another satellite within communication range. We will be referring to this new satellite as the succeeding satellite. This whole process of switching communication target is called a handover. LEO satellite constellation uses handover to be able to provide communication environment from all over the world. A well-known LEO satellite network, Iridium initiates handover about once every ten minutes. Once the destination satellite which buffers the data in its mass storage device goes out of range of the destined optical ground station, the destination satellite has to send the buffered data in its mass storage device to the succeeding satellite which will be covering the destined optical ground station after the process of handover as shown in Fig. 2(b). Since radio wave link between satellites has low capacity in comparison with optical link between satellite and optical ground station, it takes a long time to deliver the data saved in mass storage device using satellite-satellite link after handover occurred. The time it takes to deliver the buffered data to the succeeding satellite after handover increases in proportion to the amount of the data, which the destination satellite buffered in mass storage device at the time of handover. Secondly, we introduce another way to use mass storage device to minimize the time required to deliver the buffered data after handover. After handover, the current destination satellite has to wait for the previous destination satellite to send all of its buffered data over the radio wave link. Therefore, a delay is introduced, because the current destination satellite cannot send the data to the optical ground station right away. To cope with this problem, the destination satellites send the data to the succeeding satellite before the handover occur. This way, the succeeding satellite will have the buffered data before it becomes a destination satellite. However, the succeeding satellite cannot send the data until handover occur. Therefore, even if the downlink quality of the link between the current destination satellite and the optical ground station suddenly becomes significantly better, the buffered data cannot be transmitted because the succeeding satellite still have not come within the communication range of the optical ground station. In order to minimize the time required to transmit the data to the optical ground station while considering mass storage device embedded in satellite, a traffic control method which decide the usage of mass storage device embedded in the destination satellite and the succeeding satellite is necessary.

2) Problem of fluctuation in optical downlink quality: In the scenario where the downlink capacity between satellite and ground station is stable, adjacent satellites of the destination satellite should stop delivering traffic to the destination satellite when the mass storage device space on the destination satellite reach the amount that it can deliver everything before handover occur. In that case, the destination satellite will not have any data left in its mass storage device at the time of handover, because the destination satellite only stores up to the amount of data which it will be able to send before handover occur. Additionally, the amount of the data delivered to the succeeding satellite in advance is restricted to the minimum. As a result, the time required to start transmitting the data from the new destination satellite to the optical ground station is minimized. However, optical downlink is influenced by atmosphere; hence, the downlink capacity varies. The amount of the data which can be sent to the destined optical ground station before handover are unpredictable. Therefore, another method is required for optical satellite networks to effectively use of mass storage device.

III. PROPOSED TRAFFIC CONTROL METHOD TO EFFECTIVELY USE MASS STORAGE DEVICE EMBEDDED IN SATELLITE

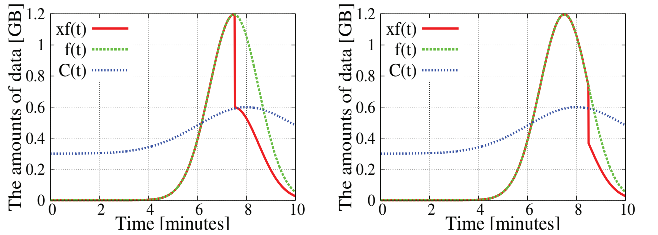
In this section, we propose a new method to control traffic in optical satellite network by using mass storage device embedded in satellite.

A. Traffic control approach to effectively use mass storage device

In order to effectively utilize mass storage device embedded in satellite, our proposed method control the amount of traffic from the adjacent satellites to the destination satellite while considering the condition of mass storage device at the destination satellite. The amount of the data which is buffered at the mass storage device embedded in the destination satellite should be restricted within the amount of which the destination satellite can send to the destined optical ground station before handover occur. When there is a long period of time until handover begins, a lot of data can be sent to the destined optical ground station. Thus, it is not a concern that the destination satellite buffered a lot of data. Conversely, in the case that there are not a lot of time left until handover, the destination satellite should not store much data in mass storage device, because the probability that the destination satellite will exit the communication range of the optical ground station while still having some unsent data in its mass storage device will increase. This means that the amount of data, which the destination satellite buffered, should be controlled according to the remaining time until handover occur. Generally, the link capacity of the downlink between the destination satellite and optical ground station should be considered. When the condition of optical downlink between the destination satellite and ground is favorable, the destination satellite can deliver a lot of data. In such cases, adjacent satellites should not restrict the amount of the traffic transmitted to the destination satellite. On the other hand, in the case where the optical downlink between the destination satellite and optical ground station is unfavorable, it is difficult to send a lot of data to the ground station. Thus, in our proposal, the adjacent satellite restrict the amount of traffic to the destination satellite and detour the traffic to the succeeding satellite, which will be entering the area where it can communicate with the optical ground station. Therefore, the amount of the data from adjacent satellites to the destination satellite is controlled according to the remaining time until handover occur and the optical downlink condition of the destination satellite at that time.

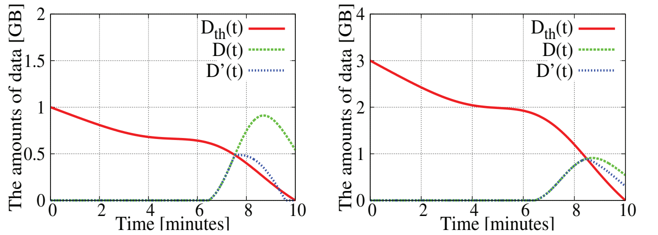
B. Threshold for the traffic control

To control the amount of the data from adjacent satellites to the destination satellite, we set a threshold which determines the timing to start reducing the amount of traffic to the destination satellite. To calculate the threshold, we utilize the amount of data in mass storage device embedded in the destination satellite. In our proposal, when the amount of data in mass storage device embedded in the destination satellite become larger than the threshold value, adjacent satellites start to reduce the amount of traffic sent to the destination satellite. Here, we define the threshold at the time of t represented as follows:



(a) $\alpha = 5$ (b) $\alpha = 15$

Fig. 3. The amount of traffic from adjacent satellites and optical downlink capacity



(a) $\alpha = 5$ (b) $\alpha = 15$

Fig. 4. The amount of the data in mass storage device of the destination satellite and threshold.

$$D_{\mathrm{th}}(t, \alpha) = \alpha \cdot \left(1 - \frac{t}{T_{\mathrm{h}}}\right) \cdot C(t), \tag{1}$$

where α is the value we control, $C(t)$ represents the optical downlink capacity of the destination satellite where t denotes the elapsed time since last handover occurred, and T_{h} represents the interval of handovers. When α is set to a large value, traffic from adjacent satellites to the destination satellite is not reduced adequately and the data will remain in the mass storage device embedded in the destination satellite at the time of handover. On the other hand, when α is set to a small value, traffic from adjacent satellites to the destination satellite decreases excessively. At the time, no matter how favorable the optical downlink capacity of the destination satellite is, the data transferred to the succeeding satellite may not be delivered to the destined optical ground station until the next handover. Therefore, in this article, we decide the appropriate value of α which optimizes the data delivery to the ground station.

C. Decision of the value of α

In this subsection, we explain how to decide the optimal value of α in our proposed method with Fig. 3 and Fig. 4. These figures show the amount of traffic from adjacent satellites, optical downlink capacity, the amount of the data in mass storage device of the destination satellite and the threshold, respectively, where the value of α is set to 5 and 15, respectively. At the beginning, we define $f(t)$ as the amount of traffic from adjacent satellites to the destination satellite. We assume that $f(t)$ follows Gaussian distribution in terms of time, which is expressed as Eq. (2), where σ and μ are the standard deviations and the mean of t, respectively.

$$g(t) = \frac{1}{\sqrt{2\pi}\sigma} \cdot \exp\left(-\frac{(t-\mu)^2}{2\sigma^2}\right). \tag{2}$$

Thus, $f(t)$ is defined as $j \cdot g(t)$ where the value of j decides the total amount of traffic in the distribution. Optical downlink capacity changes according to weather. In the case of clear weather, atmospheric transmission loss between satellite and optical ground station is approximately -4dB. When it is cloudy, atmospheric transmission loss can range from -4dB to -27dB. Furthermore, when the weather is unfavorable, it is difficult to establish a link between satellite and optical ground station because acquisition and tracking becomes more difficult with lower intensity laser, which is a result of clouds and rains. Therefore, the downlink quality will change according to the weather condition. Since weather changes with time, optical downlink capacity can be defined as a function of time. In fact, the optical downlink can drastically fluctuate, but in this article we assume a simple model in order to emphasize the feature of the optical downlink which is changing with time. Therefore, we assume that the optical downlink capacity $C(t)$ follows Gaussian distribution which is expressed as Eq. (2). $C(t)$ is expressed as $k \cdot g(t)$ where the value of k decides the actual value of the optical downlink capacity in the distribution. During this time, the amount of the data that the destination satellite stores in its mass storage device, namely $D(t)$, can be calculated as follows:

$$D(t) = \int_{t_1}^{t} \{f(t) - C(t)\}\, dt, \tag{3}$$

where t_1 is the first time when $f(t)$ becomes larger than $C(t)$. Since the destination satellite does not have to save data in mass storage device unless $f(t)$ exceed $C(t)$, $D(t)$ is calculated from t_1. When $D(t)$ reach $D_{\text{th}}(t, \alpha)$, adjacent satellites reduce the amount of the traffic to the destination satellite from $f(t)$ to $x \cdot f(t)$, and we refer to that time as $t_2(\alpha)$ where x represents the ratio of the amount of traffic that the adjacent satellites delivers to the destination satellite to the total amount of traffic that the adjacent satellites delivers. For example, $x = 1$ means that adjacent satellites send all traffic to the destination satellite and $x = 0$ means adjacent satellites do not send any traffic to the destination satellite. When α has a small value, $t_2(\alpha)$ become smaller as shown in Fig. 4(a). On the other hand, when α has large value, $t_2(\alpha)$ becomes larger as shown in Fig. 4(b). After $t_2(\alpha)$, $D(t)$ will change to $D'(t)$, which is represented as follows.

$$\begin{aligned} D'(t, \alpha) = &\int_{t_1}^{t_2(\alpha)} \{f(t) - C(t)\}\, dt \\ &+ \int_{t_2(\alpha)}^{t} \{x \cdot f(t) - C(t)\}\, dt. \end{aligned} \tag{4}$$

During this time, the amount of the data which is delivered to the succeeding satellite in advance, namely $D_{\text{detour}}(t, \alpha)$, can be expressed as following:

$$D_{\text{detour}}(t, \alpha) = (1 - x) \int_{t_2(\alpha)}^{t} f(t)dt. \tag{5}$$

Additionally, we consider the time required to transmit the data which is generated while the destination satellite has connectivity to the destined optical ground station. In order to complete delivering such data, two types of the data are transmitted. One is the data in mass storage device embedded on the destination satellite and the other is the data stored in the succeeding satellite. We define the time needed to transmit the former data as $t_3(\alpha)$, and the time needed to transmit the latter data as $t_4(\alpha)$. At the time of handover, the amount of the data in the mass storage device of the destination satellite is expressed as $D'(T_{\text{h}}, \alpha)$, and the amount of the data in the mass storage device of the succeeding satellite is expressed as $D_{\text{detour}}(T_{\text{h}}, \alpha)$.

After the handover, the $D_{\text{detour}}(T_{\text{h}}, \alpha)$ amount of data is delivered to the destined optical ground station from the succeeding satellite, but the remaining $D'(T_{\text{h}}, \alpha)$ amount of data has to be sent from the destination satellite to the succeeding satellite before arriving at the destined optical ground station. When the link capacity between satellites is C_{inter}, the amount of the data which can be sent within the interval of time t is $C_{\text{inter}} \cdot t$. Since propagation delay among two satellites is only several milliseconds in LEO constellation, we do not take into account the propagation delay. At that time, $t_3(\alpha)$ can be calculated as follows:

$$t_3(\alpha) = 0.13 \cdot \frac{D'(T_{\text{h}}, \alpha)}{C_{\text{inter}}}, \tag{6}$$

where, 0.13 means the value for coordination unit with terms. With the large value of α, $D'(T_{\text{h}}, \alpha)$ becomes larger and $t_3(\alpha)$ also becomes longer. In Fig. 3(a), $D'(T_{\text{h}}, \alpha)$ becomes zero, but in the Fig. 4(a), $D'(T_{\text{h}}, \alpha)$ still remains. At the same time, the $D_{\text{detour}}(T_{\text{h}}, \alpha)$ amount of data is delivered by using the optical downlink of the succeeding satellite. In general, optical downlink capacity is higher than radio wave link capacity, hence the succeeding satellite send $D_{\text{detour}}(T_{\text{h}}, \alpha)$ to the destined optical ground station using the remaining capacity which is used to send the data that its amount is expressed as $D'(T_{\text{h}}, \alpha)$. When the succeeding satellite deliver the data which is the amount of $D_{\text{detour}}(T_{\text{h}}, \alpha)$ completely before delivering $D'(T_{\text{h}}, \alpha)$, $t_4(\alpha)$ is calculated as follows:

$$\int_{0}^{t_4(\alpha)} \{C(t) - C_{\text{inter}}\}\, dt = D_{\text{detour}}(T_{\text{h}}, \alpha). \tag{7}$$

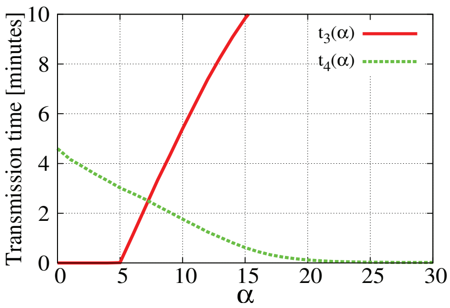
In the case that the succeeding satellite deliver all the $D'(T_{\text{h}}, \alpha)$ data and still sending the $D_{\text{detour}}(T_{\text{h}}, \alpha)$ data, $t_4(\alpha)$ is calculated as follows:

$$\begin{aligned} \int_{0}^{t_3(\alpha)} \{C(t) - C_{\text{inter}}\}\, dt + \int_{t_3(\alpha)}^{t_4(\alpha)} C(t)dt \\ = D_{\text{detour}}(T_{\text{h}}, \alpha). \end{aligned} \tag{8}$$

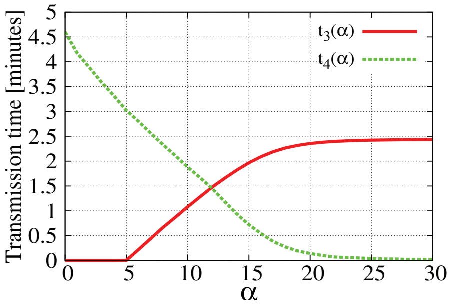
Thus, $t_4(\alpha)$ becomes small when α is set to be large, and $t_4(\alpha)$ becomes large when the value of α is small. In the result, the time required to completely deliver the data which is generated while the destination satellite cover the destined optical ground station is expressed as the larger value of $t_3(\alpha)$ and $t_4(\alpha)$. In this research, we do not consider the capacity of mass storage device embedded on satellite because the capacity of mass storage device is adequately larger than C_{inter}.

IV. Performance evaluation

In this section, we analyze the performance of the proposed method. In this analysis, we set x which is the ratio of the amount of traffic adjacent satellites deliver to 0.5. The time period between when the destination satellite starts communicating with the destined optical ground station and when



(a) Case 1



(b) Case 2

Fig. 5. The relationship between α and the time required to send the data saved in mass storage device.

handover occurs is set to 10 minutes. We analyze two different cases with different C_{inter}, because $t_3(\alpha)$ is greatly influenced by C_{inter}. In Case 1, C_{inter} is 10Mbps and in Case 2, C_{inter} is 50Mbps. In both cases, we set σ of $f(t)$ to 1.0, and μ of $f(t)$ to 6.0, and σ of $C(t)$ to 2.0, and μ of $C(t)$ to 8.0. In this analysis, α varies from 0 to 30 with a step of 1, the changes of $t_3(\alpha)$ and $t_4(\alpha)$ are analyzed. $t_3(\alpha)$ and $t_4(\alpha)$ represent the time required to send the data which is generated while the destination satellite can communicate with the destined optical ground station, hence it is desirable that these two values are restricted to small value. Therefore, we find the certain value of α which minimizes the value of both $t_3(\alpha)$ and $t_4(\alpha)$.

Fig. 5 shows relationship between α and the time required to send the generated data while the destination satellite still covers the destined optical ground station. Fig. 5(a) and Fig. 5(b) represents Case 1 and Case 2, respectively. In Fig. 5(a), when $\alpha = 0$, $t_3(\alpha)$ is zero and $t_4(\alpha)$ is the maximum value. In the situation where $\alpha = 0$, all traffic which the destination satellite cannot send to the destined optical ground station is transferred to the succeeding satellite, and the destination satellite does not store any data in its mass storage device. Thus, $t_3(\alpha)$, which is the time required to send to the data stored in the mass storage device, is zero, and $t_4(\alpha)$ which is the time required to send the data saved in the mass storage device is at maximum value. $t_3(\alpha)$ increases with the increase of α, because the amount of data which the destination satellite stores in mass storage device increases. On the other hand, $t_4(\alpha)$ decreases with the increase of α because of the reduction of the amount of the data stored in the mass storage device embedded on the succeeding satellite. When α becomes larger than 15, $t_3(\alpha)$ increases to over ten minutes. This means that the succeeding satellite cannot deliver the data completely while the succeeding satellite covers the destined optical ground station. When $\alpha = 7$, $t_3(\alpha)$ and $t_4(\alpha)$ reach the same value. When $t_3(\alpha)$ and $t_4(\alpha)$ become the same, the succeeding satellite can send the data which is generated while the destination satellite has the connection to the destined optical ground station in shortest amount time. This result shows that the amount of the generated data is the same, but the time to send that data to the destined optical ground station significantly changes by the usage of mass storage device embedded on satellite. In Fig. 5(b), since $t_4(\alpha)$ is not influenced by the link capacity among satellites, $t_4(\alpha)$ has same value that of Case 1. $t_3(\alpha)$ becomes smaller when compared with Case 1. Thus, α which makes $t_3(\alpha)$ and $t_4(\alpha)$ same value become larger. Case 2 shows that when satellite networks has high link capacity, α which minimize the time required to send the data in mass storage device become large. In this analysis, by choosing an appropriate α, it is possible to minimize the time required to send the data in mass storage device.

V. Conclusion

In this article, we addressed the challenges of using mass storage device embedded in optical satellite networks to manage tremendous amount of traffic. The optical satellite networks having mass storage device are expected as next generation satellite networks due to their many advantages such as large capacity and high speed communication. However, since the downlink condition of the optical link is dramatically affected by weather condition, it is difficult to appropriately utilize the mass storage device and optical downlink. By restricting the amount of traffic sent to the satellite, unnecessary downlink utilization can be avoided. Finally, the numerical results were presented to demonstrate the effectiveness of our proposal.

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