An Intelligent Routing Scheme Effectively Utilizing Mass Storage Embedded on Satellites to Mitigate Network Congestions

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An Intelligent Routing Scheme Effectively Utilizing Mass Storage Embedded on Satellites to Mitigate Network Congestions

Kazuma Kaneko, Yuichi Kawamoto, Hiroki Nishiyama, and Nei Kato
Graduate School of Information Sciences, Tohoku University
Sendai, Japan
{kaneko, youpsan,bigtree, kato}@it.ecei.tohoku.ac.jp

Shinichi Yamamoto, and Naoko Yoshimura
Wireless Network Research Institute, National Institute of Information and Communications Technology,
Tokyo, Japan
{yamamoto, naoko}@nict.go.jp

ABSTRACT

Recently, since many kinds of wireless devices have been widely used and a large amount of contents is available on the Internet, a network system that provides adequate services anytime and anywhere is required. In this research, we focus on satellite networks using mass storage devices to provide the above mentioned services. In this kind of network, multiple satellites are used to cover the whole surface of the earth, and each satellite is equipped with a mass storage device. By using mass storage devices, the satellite network can manage a high buffer capacity to handle large amounts of data. However, no routing method has been developed for such kind of satellite network that can utilize the storage devices and manage the large amount of data in the network effectively. In this paper, we propose a novel routing scheme for the efficient utilization of the mass storage on satellites to mitigate network congestion. The proposed method is analyzed mathematically. The numerical results validate the effectiveness of our proposed method.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network communication

General Terms

Theory

Keywords

satellite networks, storage, route control, collision congestion control

1. INTRODUCTION

In recent years, the widespread use of wireless devices such as smart-phones and tablets makes it possible to easily access to Internet anytime and anywhere. Together with the development of technologies, the demands for using high quality services have been quickly increased. For example, uploading large data such as high quality videos became more common. Using cloud computing to share and manage data has been also more popular. The total amount of data communicated in Internet may reach to several zettabytes. One more reason for the increase of network load is the development of Machine-to-Machine (M2M) that enables machines to connect and share data with others more easily. It leads to higher requirements for contemporary networks.

Terrestrial networks consist of ground-based stations. And thus, in the areas having no station such as seas or mountains, we cannot use the networks. Similarly, in the disaster areas where the stations have been broken, the networks cannot be used. For example, after the great earthquake in March 2011 in Japan, many people have suffered from the lack of communications. Therefore, the next generation networks need to not only handle a large amount of data but also provide easy Internet access to users anytime and anywhere. Because of these factors, satellite networks have attracted much attention.

Particularly, we focus on the satellite networks using mass storage devices [1]. In this kind of networks, each satellite can keep big amount of data in the storage and provide high quality services to many people. Satellite networks provide worldwide communication environment since they have wide coverage and the advantages of simultaneous transmissive communication. In disaster areas, we can use them instead of the destroyed ground network systems. The satellite networks using mass storage devices are considered as a good candidate for next generation network systems to manage large amount of data. However, in the previous researches on routing method for the satellite networks using mass storage devices, there are not any methods efficiently utilizing the network and the storage devices. Therefore, in this paper, we propose a new routing method which utilize the mass storage devices on the satellites in order to manage high amount of data in the satellite networks. We also analyze the utilization of the links with mathematical expressions. Moreover, we confirm the effectiveness of our proposed routing scheme and the correctness of the analysis on the link

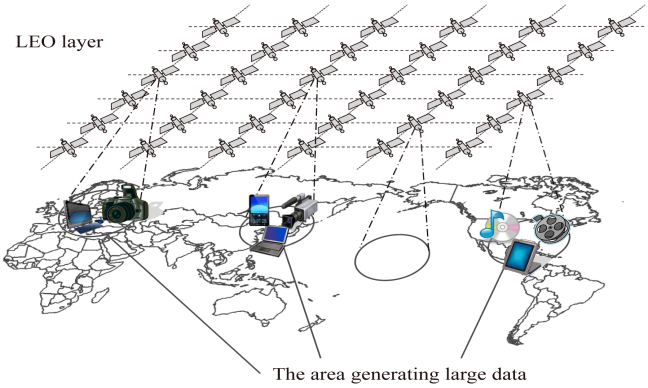


Figure 1: An example of a constellation constructed by LEO satellites using mass storage devices.

utilization by using numerical calculations.

The remainder of this paper is organized as follows. Section 2 describes general satellite constellations and the existing routing methods for satellite networks. The proposed routing method and the analyses regarding the link utilization are introduced in Section 3. The numerical results are presented in Section 4. Finally, this paper is concluded in Section 5.

2. SATELLITE CONSTELLATIONS AND EXISTING ROUTING METHODS

2.1 General satellite constellations

Satellites are generally categorized into Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Earth Orbit (GEO) satellites according to their altitude [2] [3]. Each satellite constellation has different advantages [4] [5]. In these constellations, we take particular note of LEO satellite constellations for their lower delay and electric power saving aspects. Since they have lower altitude orbit than GEO and MEO satellites, they can communicate with small antennas on the ground. As a result, LEO satellites are suitable for mobile communications. However, in order to cover all over the world, it is necessary to build a network between LEO satellites. Iridium is a famous LEO satellite constellation which is a system to provide worldwide communication environment. It consists of 66 satellites orbiting 780km high, has a mesh type topology which constructs 6 orbits, and has 4 Inter Satellite Links (ISLs) with adjacent satellites. In this paper, we focus on networks consisting of mesh type LEO satellite constellations and each satellite has a mass storage device.

2.2 Existing routing method and its shortcomings

In satellite networks, traffic is sent from satellite earth stations to LEO satellites, and then go through other LEO satellites to go to the destination. To realize efficient traffic delivery, the route control of traffic is necessary. Most of the existing route control methods are implemented based on the Dijkstra's Shortest Path (DSP) algorithm, which selects the path whose link cost is minimal. Transmission delay or hop count is generally utilized as the link cost in DSP [6] [7]. Since DSP is known as one of the simplest routing schemes, it has been employed in various networks including satellite networks. However, traffic distribution on the earth is very inhomogeneous because users of the network tend to converge to big cities against sea or mountain areas. The distribution of the amount of generated traffic is similar to that of population. Thus, much traffic gathers to some LEO satellites covering populated areas. Traffic congestion causes the decrease in the performance of the network such as packet drop, throughput degradation, and the increase of delay. To avoid the congestion, many route control methods for satellite networks have been developed based on DSP [8] [9] [10]. As one example, Explicit Load Balancing (ELB) is proposed as a traffic control method that can handle acute changes of traffic [11]. In ELB, each satellite constantly measures its queue occupancy as an indicator of traffic loads. Each satellite also exchanges congestion information. The traffic detouring is performed depending on the condition of the traffic load. As a result, when a satellite has heavy traffic load and congestion occurs, its load is immediately decreased by traffic detouring. Even though ELB is able to mitigate the congestion at relay satellites, there has not been any method which can efficiently avoid the congestion at the destination concentrating high traffic.

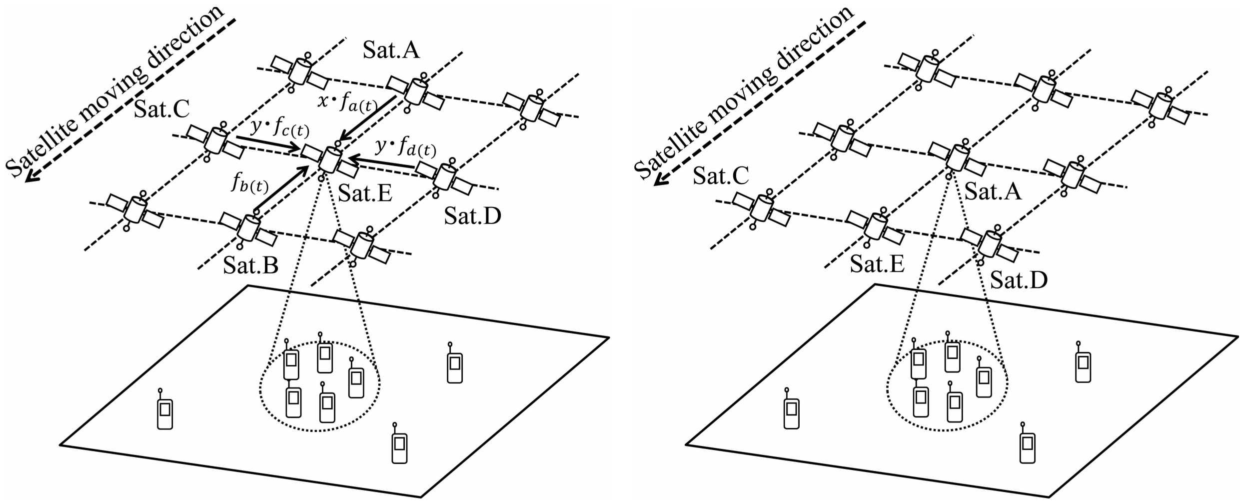
In order to come up with a solution for that problem, we consider satellite networks where each satellite has a mass storage device. Satellites can save and bring the data when they orbit the earth. In other words, satellites are able to deliver a packet to destination without using the link among satellites. However, an efficient routing method is required to take such advantage of the embedded mass storage devices.

3. PROPOSED ROUTING METHOD CONSIDERING STORAGE DEVICES

We consider a simple scenario as shown in Figure 2 in order to make a clear explanation for our method. In this scenario, at first, satellite E covers the area where there is traffic concentrating. Satellite E has four links among adjacent satellites. These satellites move together in the direction of the arrow in Figure 2. After that, the hand-over from satellite E to satellite A occurs and satellite A moves to this area as shown Figure 2(b).

3.1 Deterioration of the link utilization

In this section, we propose a new routing method to improve link utilization and avoid network congestion. For satellite networks, roundabout traffic has negative effects because it wastefully use links that do not need to be used. On the other hand, since unnecessary detouring leads to delay, traffic should only use the necessary links. Thus, link utilization improves when only necessary links are used, and degrades when wasteful links are used. When much traffic concentrates on one satellite, the congestion might occur. In the case of not having storage device, satellites cannot save packets temporally, and thus adjacent satellites continue sending packets to the satellite having congestion. In our new routing method, adjacent satellites reduce the amount of traffic to the satellite having congestion by detouring or saving some traffic. Although our routing method is proposed for general cases, in order to keep the simplicity of the explanation, the proposed algorithm is explained based



(a) Before hand-over (b) After hand-over

Figure 2: Considered model.

on the above mentioned scenario.

When our new routing method is not applied, the amount of the traffic from satellite A to E at the time of t is defined by $f_a(t)$, and those from B, C, D are defined by $f_b(t)$, $f_c(t)$, and $f_d(t)$, respectively. t_h is the time when satellite E moves out of the communication range of the destination. In this research, we only consider the traffic that is sent to destination through satellite E. The amount of all traffic to satellite E, $F(t)$ is expressed as the following equation.

$$F(t) = f_a(t) + f_b(t) + f_c(t) + f_d(t). \tag{1}$$

We assume that all satellites have the ability to send the traffic with the amount of T_{capacity} to the destination per time unit. Since satellite E covers the area where there is much traffic concentrating, it is likely that $F(t)$ becomes larger than T_{capacity}. If $F(t)$ is greater than T_{capacity}, either satellite E has to save data to storage device or adjacent satellites need to reduce the amount of traffic to satellite E.

Firstly, we consider the case where satellite E saves all the which is over T_{capacity} in storage device. When satellite E moves out of the communication range of the destination at the time t_h, satellite A covers the area that was previously covered by satellite E as shown in Figure 2(b). In this case, if satellite E saved the data in its storage device, it has to send that amount of data to satellite A using satellite-satellite links. To prevent using these links, we consider the another case where adjeacent satellites reduce the amount of traffic to satellite E by sending that traffic to satellite A beforehand. Since satellite A saved that data in its storage device, it can send that data to the destination without using any more satellite-satellite links. As a result, the link utilization will be improved. On the other hand, if the traffic from adjacent satellites to satellite E is too small, satellite-destination link cannot be used adequately and it deteriorates the utilization of satellite-destination links. Therefore, it is necessary to maximize the use of the link between satellite E and destination, and minimize the amount of data that satellite E needs to send to satellite A. It is important to note that futher describe how adjacent satellites send traffic to satellite A. Satellite A does not send traffic and save it in its storage device, but another satellites have to send traffic to satellite A using satellite-satellite links. Satellite C and satellite D have to use two satellite-satellite links and satellite B has to use four satellite-satellite links. Obviously, the amount that adjacent satellites send to satellite A should change taking into account the positions of the satellites.

When $F(t)$ reaches T_{capacity}, satellite E sends signaling packets to its adjacent satellites. Satellite A which received this signaling packets reduces the amount of traffic actually flowing to satellite E to $xf_a(t)$, where x represents the ratio of the amount of traffic when our method is applied to amount of traffic when the method is not applied. $x = 1$ means satellite A sends all traffic with the destination is satellite E, and $x = 0$ means satellite A does not send any such traffic. Similar to satellite A, after receiving signaling packets from satellite E, satellite C and D reduce the amount of traffic actually flowing to satellite E to $yf_c(t)$ and $yf_d(t)$, respectively. Note that the value of x and y imply all cases that only satellite E saves data to its storage device, or only the adjacent satellites reduce the amount of traffic to satellite E, or both. When satellite C and D reduce their traffic, based on the moving direction of the constellation as shown in Figure 2, the remaining traffic from satellite C and D should be detoured to satellite A. After that, satellite A can save those data and directly send to the destination because satellite A will cover the area instead of satellite E. The amount of traffic which satellite C and satellite D detour to satellite A are $(1-y)f_c(t)$ and $(1-y)f_d(t)$, respectively. After the adjustment, the amount of traffic which adjacent satellites actually send, $F'(t)$, becomes the following equation.

$$F'(t) = xf_a(t) + f_b(t) + y\{f_c(t) + f_d(t)\}. \tag{2}$$

If the adjacent satellites reduce the amount of traffic to satellite E, but $F'(t)$ is still greater than T_{capacity}, satellite E saves the data that cannot be sent to destination. If $F'(t)$ becomes below T_{capacity} after using storage device on satellite E, satellite E sends the data saved in its storage device to the destination.

3.2 Improvement of the link utilization

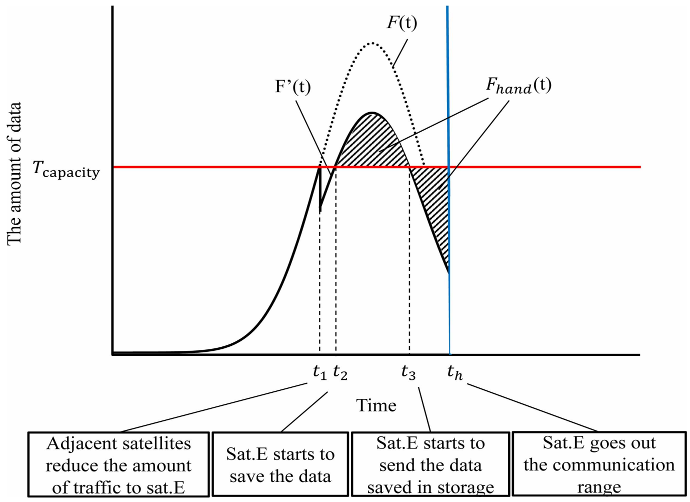


Figure 3: The relationship between $F(t), F'(t)$, and T_{capacity}.

In this section, we compare the link utilization in two cases of using storage device on satellite E or on satellite A.

We assume that every adjacent satellites of satellite E generates the same amount of traffic having Gaussian distribution in terms of time, which is expressed as Eq. 3, where σ is the standard deviations of t, and μ is the mean of t.

$$f(t) = \frac{1}{\sqrt{2\pi\sigma}} \exp\left(-\frac{(t-\mu)^2}{2\sigma^2}\right). \quad (3)$$

Gaussian distribution has the peak at μ, and traffic decreases gradually from this peak but is limited by zero. The shape of the distribution depends on the value of σ. $F(t)$ and $F'(t)$ can be calculated as follows.

$$F(t) = 4f(t). \quad (4)$$

$$F'(t) = (1 + x + 2y)f(t). \quad (5)$$

We consider the case $F(t)$ becomes larger than T_{capacity}, when satellites need to use storage device. The time when $F(t)$ becomes over T_{capacity} is defined by t_1 as shown Figure 3. This parameter is related to traffic distribution and T_{capacity}. As mentioned earlier, adjacent satellites reduce the traffic to $F'(t)$ at t_1. In the case $F'(t)$ becomes over T_{capacity} in spite of reducing traffic to satellite E, we call that time t_2. And when $F'(t)$ falls below T_{capacity}, we call that time t_3. Similar to t_1, t_2 and t_3 change with the changes of traffic distribution and T_{capacity}. In addition, t_2 and t_3 are related to the amount of traffic from adjacent satellites, which are affected by x and y. According to traffic distribution, relationship with t_3 and t_h is categorized in two types, $t_3 \leq t_h$, and $t_h < t_3$. Figure 3 indicates only one case which is $t_3 \leq t_h$.

The amount of data that satellite E has to send to satellite A after hand-over occurs, F_{hand}, is expressed as follows.

$$F_{hand} = \int_{t_2}^{t_h} \{F'(t) - T_{\text{capacity}}\} dt \quad (6)$$

In Figure 3, F_{hand} is indicated by the shaded area. When $F'(t)$ is larger than T_{capacity}, satellite E starts to save the data in its storage device. After $F'(t)$ falls below T_{capacity}, satellite E sends the data saved in its storage device. If the amount of the data that satellite E temporarily saved is larger than the amount of data that satellite E can send until the hand-over occurs, F_{hand} has a positive value. This means that satellite E has to send that data to satellite A after the hand-over. On the other hand, if the amount of the data that satellite E temporarily saves is smaller than the amount of data that satellite E can send until hand-over occurs, F_{hand} has a negative value. In this case, no traffic is sent from satellite E to satellite A after the hand-over. However, when satellite E does not use the satellite-destination links at its maximum, the link utilization between satellite and destination decreases. As a result, to maximize link utilization, satellite E should always send traffic with an amount equal to T_{capacity} to the destination, and thus, the incoming traffic to satellite E is limited such that no traffic is transmitted from satellite E to satellite A after the hand-over. This results in a value of $F_{hand} = 0$. In the next section, we analyze the existence of x and y that makes $F_{hand} = 0$.

Table 1: parameter settings

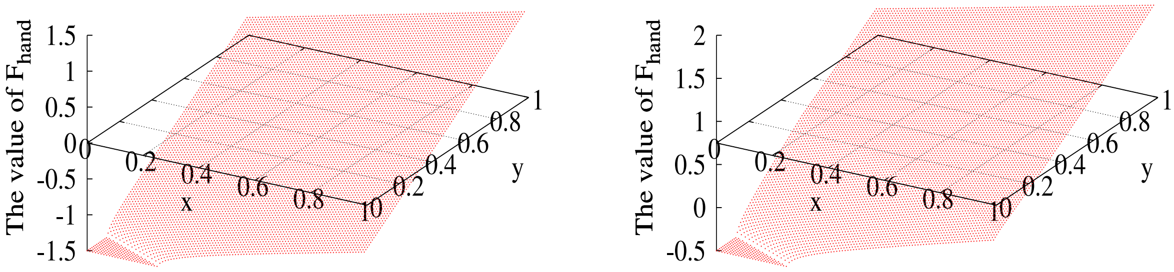
	case1	case2
σ	1.0	1.0
μ	8.0	9.0
x	0.00-1.00	0.00-1.00
y	0.00-1.00	0.00-1.00

4. NUMERICAL ANALYSIS

In this section, we aim to verify the relationship between the utilization of satellite-satellite links and that of satellite-destination links. Moreover, we declare the existence of the optimal amount which adjacent satellites send to satellite E with some numerical calculation results.

The parameter settings that characterize traffic are summarized in Table 1. In this numerical analysis, T_{capacity} is set to 0.5GB. The time period between when satellite E starts covering the destination to when the hand-over occurs is set to 10 minutes. We analyze two different cases that are described as follows. In Case 1, we set σ to 1.0 and μ to 8.0, and the percentage of traffic amount x and y varies from 0.00 to 1.00 with a step of 0.01. If there is a particular combination of x and y which makes $F_{hand} = 0$, it means that satellite E always send T_{capacity} traffic and there are no traffic needed to send from satellite E to satellite A after hand-over. In short, we find the optimal combination of x with y such that the link utilization becomes maximum. In Case 2, we set σ to 1.0 and μ to 9.0, and vary x and y in the same way as the Case 1. By indicating particular combination of x and y which makes $F_{hand} = 0$ using another parameter, it can be said that the optimal combination of x and y exists regardless of the traffic.

Figure 4 shows the relationship between the amount of traffic from adjacent satellites and the storage device utilization of satellite E. Figure 4(a) and Figure 4(b) represents Case 1 and Case 2, respectively. In Figure 4(a), F_{hand} increases with the increase of x and y. In the area with small x and y, F_{hand} keep a constant value. In this area, x and y is too small and $F'(t)$ does not reach T_{capacity}. In this



(a) Case 1

(b) Case 2

Figure 4: The relationship between the amount of traffic from adjacent satellites and the utilization of storage device on satellite E.

case, t_2 and t_3 do not exist, so we can not calculate F_{hand}. Therefore we use the minimum value of F_{hand} for F_{hand} in the area. The plane of F_{hand} crosses zero plane at particular x and y, which means that the optimal combination exists and that is the optimum value. Also, in Figure 4(b), the plane F_{hand} crosses zero plane at different value of x and y, so the optimal combination of x with y exists. These results show that there is a combination of x and y that makes the link utilization maximum regardless of the traffic.

5. CONCLUSION

In this paper, we proposed a new routing method for satellite networks using mass storage devices, which is a good candidate for next generation networks to manage large amount of data. By applying our new routing method, satellite networks can mitigate congestion due to the concentration of traffic. Furthermore, we analyzed the link utilization of satellite-satellite and satellite-destination links. From the analysis of over use of the satellite-satellite links and inadequate use of the satellite-destination links, the existence of the optimal amount of traffic from adjacent satellites to the satellite having congestion in terms of maximizing link utilization is indicated. Finaly, we showed that the appropriate routing method achieves to avoid congestion for satellite networks without wasteful consumption of network resource.

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