Traffic Distribution to Mitigate Downlink Congestion in Two-Layered Satellite Networks

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***Abstract*—Satellite networks have received increasing attention as a means to provide a next generation network able to realize a ubiquitous network. Satellite networks in general can be classified into Geostationary Earth Orbit (GEO) satellite networks or Non-Geostationary Earth Orbit (NGEO) satellite networks. A special type of satellite networks which can be constructed by layering NGEO satellite networks is called the Multi-Layered Satellite Networks (MLSNs). In MLSNs, various traffic paths can be used as detour paths, which allows the load distribution among satellites. With this feature, even if a disaster strikes and some satellites suffer from heavy traffic load, congestion can be avoided by using these traffic paths in the MLSN. In this paper, we propose a route control method which aims at effectively avoiding congestion occurrence in MLSNs. The performance of our proposed method is evaluated through computer simulations.**

I. Introduction

In recent years, realizing a ubiquitous network is important along with the increasing popularity of mobile devices such as cellular phones and smart phones. However, since the companies tend to build their communication infrastructures in urban areas, other areas, like oceans and mountains, suffer from the lack of an efficient communication system due to the high construction costs. As a result of this, and in order to achieve a ubiquitous network, we need to set up an environment for the users to be served anywhere without the need for a communication infrastructure. Satellite networks have attracted much attention a ubiquitous networks.

The satellite networks constructed by Non-Geostationary Earth Orbit (NGEO) satellites are called NGEO satellite networks. The NGEO satellite with a relatively low altitude is called Low Earth Orbit (LEO) satellite, and the NGEO satellite with altitude higher than that of a LEO satellite is called Medium Earth Orbit (MEO) satellite. The NGEO satellite network is constructed from many NGEO satellites since NGEO satellites always move closer to the surface of the earth. This satellite cluster that comprises many satellites is called satellite constellation, e.g., Iridium [1], NeLs [2], and Spaceway NGSO [3]. Due to the lower satellite altitude, compared with Geostationary Earth Orbit (GEO) satellites, terrestrial terminals are able to communicate with NGEO satellites with shorter propagation delay and lower power consumption. As a consequence, NGSO satellites is a suitable candidate for real time communication and a mobile terminal device with a small antenna can still communicate with NGEO satellites.

The above mentioned satellite networks make it possible for users on the ground to use network services provided by a number of satellites covering the surface of the earth. Recently, the researchers are investigating on how to utilize such networks in the cases of natural disaster. By setting up an antenna for mobile satellite communication such as Very Small Aperture Terminal (VSAT) [4] and in-vehicle wireless base station in the disaster area , we are able to use network services over satellite networks. Therefore, satellite networks make it possible to access external network even if the communication system on the ground is down.

More recently, Multi-Layered Satellite Networks (MLSN) that are constructed by layering NGEO satellite networks are under intense investigation [5]. In MLSN, the layer consisting of a number of LEO satellites is called LEO layer, and the layer consisting of a number of MEO satellites is called MEO layer. In MLSN, there are six different links, i.e., inter satellite links in LEO and MEO layers, up and down inter-layer links, and up and down links between LEO layer and ground, which are referred to as LEO-LEO, MEO-MEO, LEO-MEO, MEO-LEO, ground-LEO, and LEO-ground. These links make it possible to use various traffic paths between source and destination. By using the various traffic paths as detour paths, the distribution of traffic load among satellites is possible. As an example, at the time of disaster, some satellites suffer from a heavy traffic load since there are many users trying to access the external network through satellite communication instead of using terrestrial networks which may be destroyed in the disaster area. In such situation, and by using MLSN, the distribution of traffic load among satellites is possible since various traffic paths is available as detour paths.

In order to achieve a sufficient distribution of traffic load among the satellites in MLSN, an appropriate route control method is required. In literature, there are several route control methods aiming at traffic load distribution among satellites in MLSN. However, existing route control methods cannot avoid the congestion at LEO-ground link since these methods can only avoid the congestion at LEO-LEO link. Therefore, in this paper, we propose a novel route control method to avoid the congestion at LEO-ground link and to achieve a sufficient traffic load distribution among satellites in MLSN.

The remainder of this paper is organized as follows. Section II introduces the related work and points out the problem of existing route control methods. In order to solve this problem, we propose a novel route control method in Section III. Then, we evaluate the performance of our proposed method in section IV. Finally, the paper is concluded in Section V.

II. Related work

In this section, we introduce some of the existing route control methods. The existing route control methods which aims at achieving a sufficient traffic load distribution can be divided into two groups. The first group detours traffic flexibly to adapt it to change in the congestion situation. The second group detours traffic to avoid congestion occurrence in advance. So, we introduce Explicit Load Balancing (ELB) [6], [7], [8] as a representative of the former and distribution method of traffic to use multi-layers equally [9] as a representative of the latter. Additionally, we point out the problem of these existing route control methods.

A. Explicit Load Balancing

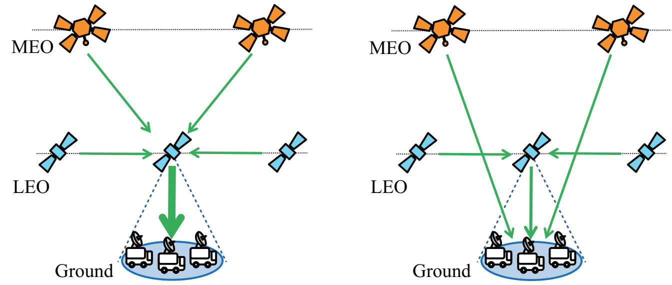
When numerous traffic is transmitted among LEO satellites, some LEO satellites are used as relay points for the traffic. When this numerous traffic is being relayed in a specific LEO satellite, the risk of congestion occurrence at this LEO satellite increases.

In order to solve this problem, Explicit Load Balancing (ELB) [6], [7], [8] is proposed as a traffic control method that can avoid this type of congestion. In ELB, if a LEO satellite suffers from a heavy traffic load, it sends signaling packets to adjacent LEO satellites for reducing the traffic from them. First, each LEO satellite periodically measure its own queue occupancy in order to detect a congestion. LEO satellites set threshold for their own queue occupancy. If the queue occupancy at a LEO satellite exceeds the threshold, this LEO satellite sends a signaling packet called Busy State Advertisement (BSA) to the adjacent LEO satellites. Finally, the adjacent LEO satellites, which have received the BSA detour traffic, decrease the amount of traffic they send to that congested LEO satellite. As a result, the congestion can be removed.

B. Distribution method of traffic using multi-layers equally

Among route control methods, Dijkstra Shortest Path (DSP) [10] is well known as a simple one. However, if the DSP is used as a route control method for MLSN, numerous traffic will be transmitted to LEO layer. because the altitude of MEO satellite is higher than that of LEO satellites, which increases the risk of congestion occurrence. On the other hand, in MEO layer, utilization of the MEO satellites decreases.

In order to solve this problem, traffic distribution method to fairly utilize using multi-layers has been proposed [9]. In this route control method, there is a threshold for end-to-end delay. If the end-to-end delay is below this threshold, the traffic is routed to go through only LEO satellite. On the other hand, if the end-to-end delay exceeds this threshold, the traffic is routed to go through MEO satellite. This threshold is calculated based on network capacity of each layer. As a result, numerous traffic is not always transmitted to one layer, and multi-layers can be used equally by setting appropriate threshold.



(a) In traditional route control methods (b) In the proposed method

Fig. 1. Traffic path from MEO and LEO to ground

C. Problem in existing methods

In the above mentioned route control methods, traffic is detoured in LEO layer or between LEO layer and MEO layer. In other words, existing route control methods can avoid or mitigate congestions only within LEO layer. On the other hand, LEO-ground links are possible to experience congestions when a numerous number of terrestrial terminals simultaneously try to communicate through a MLSN in case a disaster. Therefore, we propose a new route control method to avoid the congestion at LEO-ground link.

III. Proposed method

In this section, we describe our proposed method which aims to solve the problem of the existing route control methods. First, we introduce a new link as detour path. Second, we propose a new route control method to distribute the traffic load efficiently. By using our envisioned route control method, we have the ability to avoid the congestion at LEO-ground link.

A. Addition of a new link

Existing route control methods for MLSN are based on that there are six different links in MLSN. In addition to these links, we consider a new link from MEO satellite to ground, referred to as MEO-ground link. If a terrestrial terminal transmits traffic by using existing traffic paths, traffic must go through LEO satellite covering destination area regardless of route as illustrated in Fig. 1(a). Therefore, in the areas where satellites are highly utilized, LEO-ground link will become a bottleneck. On the other hand, if a terrestrial terminal transmits traffic by using MEO-ground link, traffic does not need to go through the LEO satellite covering the destination area as illustrated in Fig.1(b). In other words, traffic can be transmitted without going through the LEO satellite covering destination area. Therefore, by using a direct link from MEO satellite to an individual terrestrial terminal as detour path, we can decrease the amount of traffic passing through the LEO satellite covering the destination area.

B. The route control method considering congestion situation

In order to use MEO-ground link as detour path efficiently, we propose a novel route control method. In our envisioned route control method, first, LEO satellites share the position information of the congested area on the ground. Second, LEO satellites judge whether or not the destination area is congested, and then select the appropriate route.

In this paper, we refer to the area that satellites are highly utilized as a congestion area. In disaster area, satellites are highly utilized since communication system on the ground is down. So, disaster area is an example of a congestion area. First of all, each satellite observe the amount of traffic transmitted to ground. If the amount of traffic is constantly big, the LEO satellite defines the coverage area as a congestion area. Additionally, LEO satellite covering the congestion area broadcasts position information to other LEO satellites in order to share the information among them. Therefore, all the LEO satellites have the ability to figure out where the congestion area is.

Secondly, LEO satellites grasp congestion situation of destination area by taking into account this position information, and select the route. When LEO satellite receives traffic from a terrestrial terminal in the coverage area, LEO satellite determines if the destination area is a congestion area or no. If the destination area is not a congestion area, the LEO-ground link at the destination area seems not to be a bottleneck. In this case, LEO satellite that received the traffic from a terrestrial terminal transmits the traffic to an adjacent LEO satellite, and traffic go through only LEO satellites to destination area as illustrated in Fig. 2, i.e., route from Source 1 to Destination 1. On the other hand, if the destination area is recognized as a congestion area, the LEO-ground link at the destination area seems to be a bottleneck. In this case, LEO satellite that received traffic from a terrestrial terminal detour a part of traffic to the nearest MEO satellite, and the detour traffic go through only MEO satellites to the destination area as illustrated in Fig. 2, i.e., route from Source 2 to Destination 2. By selecting the route as above, amount of traffic from LEO satellite covering the congestion area to the congestion area terminals decreases. Therefore, LEO satellite covering the congestion area can avoid the congestion at LEO-ground link.

The amount of traffic which the LEO satellite detours is a crucial factor. If the amount of detour traffic is too small, LEO satellite cannot avoid congestion since LEO satellite fails to avoid the congestion at LEO-ground link. On the other hand, if the amount of detour traffic is too big, the risk of congestion at MEO-ground link. In other words, it is necessary to detour traffic appropriately to prevent both MEO satellites and LEO satellites from congestion. We refer to the rate that determine the amount of detour traffic as *distribution rate*, D, and the value of D is same among LEO satellites. Therefore, it is possible that LEO satellites and MEO satellites covering the congestion area transmit traffic to congestion area at this *distribution rate*. Additionally, *distribution rate* is determined by the number of links from the satellites to the congestion area and the bandwidth of these links. LEO satellite that received traffic from a terrestrial terminal calculates the sum of the link bandwidth from MEO satellites to congestion area and the sum of the link bandwidth from LEO satellite to congestion area. *distribution rate* is then calculated by the ratio of these sum. The sum of the bandwidth of LEO-ground links in the destination area as B_{LEO}, and the sum of the link bandwidth from MEO satellites to destination area as B_{MEO}. The expression for the value of D is developed as follows:

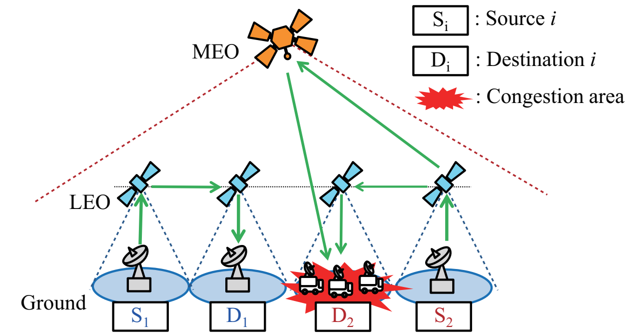


Fig. 2. The route selection considering congestion situation of destination.

$$D = \frac{B_{\mathrm{MEO}}}{B_{\mathrm{LEO}} + B_{\mathrm{MEO}}} \tag{1}$$

Assume that LEO-ground and MEO-ground links have the same bandwidth, Eq.(1) can be further simplified. By referring to the number of links from LEO satellites to the congestion area as L_{LEO} and the number of links from MEO satellites to the congestion area as L_{MEO}, D can be expressed by using L_{LEO} and L_{MEO} as follows:

$$D = \frac{L_{\mathrm{MEO}}}{L_{\mathrm{LEO}} + L_{\mathrm{MEO}}} \times 100 \tag{2}$$

By calculating the *distribution rate* as explained above, the links from LEO satellite to congestion area and the links from MEO satellites to congestion area are able to be used with same traffic load. It will be possible to prevent the LEO-ground and MEO-ground links from satellites to ground from becoming bottleneck.

IV. Performance Evaluation

In this section, we evaluate the effectiveness of our proposed method with Network Simulator version 2 (NS-2) [11]. First, we assess the appropriateness of method for calculating the *distribution rate*. Second, we make a performance comparison between our proposed route control method and an existing one.

A. Simulation setup

We set the network configuration parameters as shown in Table I. Also, the traffic characteristics used in the simulations are shown in Table II. A scenario where a disaster occurs in

TABLE I
SIMULATION PARAMETERS

Number of LEO satellites	66
Number of MEO satellites	20
Number of terrestrial terminals	100
LEO satellite altitude	780 km
MEO satellite altitude	10352 km
LEO-LEO Link bandwidth	15 Mbps
MEO-MEO Link bandwidth	15 Mbps
LEO-MEO and MEO-LEO Link bandwidth	15 Mbps
LEO-ground and ground-LEO Link bandwidth	5 Mbps
MEO-ground Link bandwidth	5 Mbps
Queue length	20 packets

TABLE II
TRAFFIC CHARACTERISTICS

Traffic type	On/Off traffic
On/Off distribution	Pareto distribution
Average On/Off interval	200 ms
Packet size	500 Bytes
Number of flows	100

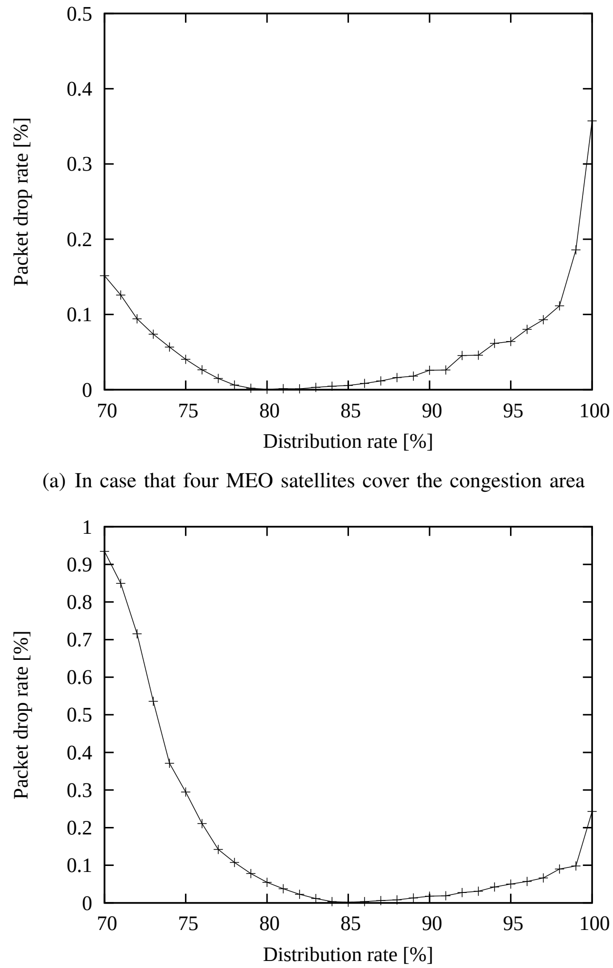
one area is simulated. In other words, we have one congestion area on the earth. Moreover, we assume traffic is uniformly transmitted to congestion area from all directions. Additionally, position information of congestion area has already been shared among LEO satellites, and all LEO satellites have figured out where the congestion area is. We assume a two-layered MLSN constructed by integrating Iridium constellation as LEO layer and Spaceway NGSO constellation as MEO layer. In Iridium constellation, there are 6 planes with 11 satellites per plane. In Spaceway NGSO constellation, there are 4 planes with 5 satellites per plane.

In the first experiment, we change the *distribution rate* from 70% to 100% in 1% increments and observe the packet drop rates over the whole network. Moreover, The placement of the congestion area has two patterns that the number of MEO satellites covering the congestion area is 4 or 6. We set the traffic rate to be 1100 Kbps at the former case and 1500 Kbps at the later.

In the second experiment, we use DSP as an existing route control method to make a performance comparison between our proposed method and an existing route control method. Here, we change the traffic rate from 20 Kbps to 800 Kbps in 20 Kbps increments, and observe the packet drop rates over the whole network and the total throughput for performance evaluation.

B. Simulation results

Fig. 3 shows the results of the first experiment, i.e., packet drop rate for different values of *distribution rate*. In Fig. 3(a) where the number of MEO satellites covering the congestion area is set to four, packet drop rates have an absolute minimum at the time when the *distribution rate* is around 80%. In Fig. 3(b) where the number of MEO satellites covering the congestion area is equal to six, packet drop rate have an absolute minimum at the time *distribution rate* is around 85%. The minimum point of the later is higher than the former



(a) In case that four MEO satellites cover the congestion area

(b) In case that six MEO satellites cover the congestion area

Fig. 3. Changing in packet drop rate for different *distribution rate*.

since the sum of the link bandwidth from MEO satellites to congestion is bigger than the former. When the *distribution rate* increases from 70% to a minimum point, the amount of traffic that is transmitted through the LEO satellite to ground decreases. For this reason, packet drop rate over the whole network can be decreased. However, when the *distribution rate* increases from the minimum point, the amount of traffic that is transmitted through MEO-ground links increases and the packet drop rate over the whole network increases. In our proposed method, the *distribution rate* is calculated by using Eq. (2). In case of Fig. 3(a) where four MEO satellites cover the congestion area, the distribution rate become equal to 80%. In the same way, we can calculate the *distribution rate* to be 85.7% in case of Fig. 3(b). As we can see, the calculated values are very close to those values obtained through the experiments in each case. It is shown that the method for calculating the *distribution rate* is validated.

Fig. 4 shows the variation in the packet drop rate of the existing route control method, i.e., DSP, and the proposed route control method. In the existing route control method,

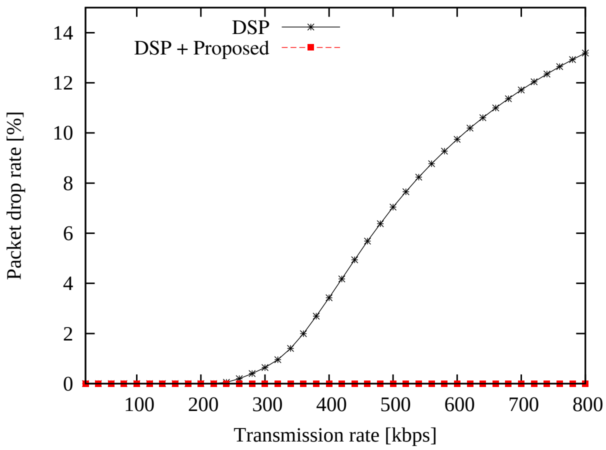


Fig. 4. The variation of packet drop rate with traffic rate

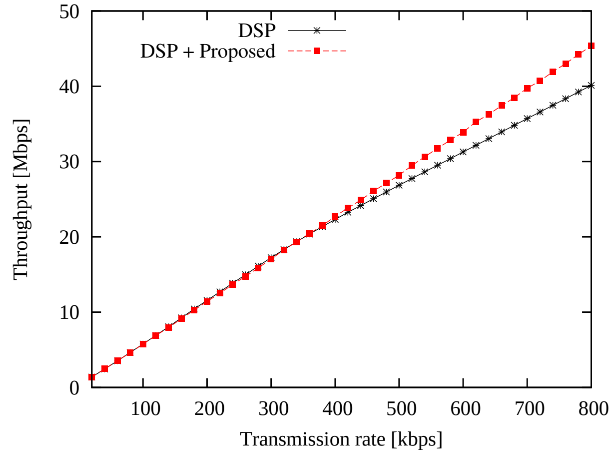


Fig. 5. The variation of throughput with traffic rate

packets start to drop when traffic rate increases from about 240kbps. This result shows congestion occurs in MLSN when traffic rate is higher than about 240kbps in the existing route control method. On the other hand, there is no packet drop in the proposed route control method as the traffic increases to 800 kbps. We are assured that the proposed method is able to reduce the packet drop rate. This is attributed to the fact that proposed route control method have avoided the congestion of LEO-ground link. Fig. 5 shows the variation in the throughput in the existing route control method and the proposed route control method. Both methods have about the same throughput when traffic rate increases to about 400 kbps. As the traffic rate increases further, the proposed route control method have higher throughput than the existing route control method. We are assured that the proposed method is able to enhance throughput. This is attributed to the fact that a lot of packet drop as traffic rate increase from about 400 kbps in the existing route control method.

From these results, we have confirmed the effectiveness of our proposed method.

V. Conclusion

In recent years, MLSN constructed by integrating LEO and MEO satellite networks are under intense investigation. In order to achieve a sufficient distribution of traffic load among satellites in MLSN, an appropriate route control method is needed. However, existing route control methods for MLSN cannot avoid the congestion at LEO-ground link.

In this paper, we have proposed a route control method to avoid the congestion of LEO-ground link. First, we introduced MEO-ground link as a new link in addition to existing links. By using this link, terrestrial terminals had the ability to transmit traffic to congestion area without going through LEO satellite covering the destination congested area. Second, we proposed a new routing control method that use a new link as a detour path. In this routing control method, by considering the congestion situation of the destination area in the route decision process, it was possible to avoid the congestion at LEO-ground link. Finally, we had confirmed the effectiveness of our proposed method through simulations.

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