A Novel Adaptive Routing Algorithm for Delay-Sensitive Service in Multihop LEO Satellite Network

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Abstract

The Low Earth Orbit satellite network has the unique characteristics of the non-uniform and time-variant traffic load distribution, which often causes severe link congestion and thus results in poor performance for delay-sensitive flows, especially when the network is heavily loaded. To solve this problem, a novel adaptive routing algorithm, referred to as the delay-oriented adaptive routing algorithm (DOAR), is proposed. Different from current reactive schemes, DOAR employs Destination-Sequenced Distance-Vector (DSDV) routing algorithm, which is a proactive scheme. DSDV is extended to a multipath QoS version to generate alternative routes in active with real-time delay metric, which leads to two significant advantages. First, the flows can be timely and accurately detected for route adjustment. Second, it enables fast, flexible, and optimized QoS matching between the alternative routes and adjustment requiring flows and meanwhile avoids delay growth caused by increased hop number and diffused congestion range. In addition, a retrospective route adjustment requesting scheme is designed in DOAR to enlarge the alternative routes set in the severe congestion state in a large area. Simulation result suggests that DOAR performs better than typical adaptive routing algorithms in terms of the throughput and the delay in a variety of traffic intensity.

Keywords: Adaptive routing, Delay constraint, Multihop Low Earth Orbit (LEO) Satellite networks, quality of service (QoS)

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1. Introduction

Low Earth Orbit (LEO) satellite networks provide us with wide coverage including rural areas and oceans, and have been widely used on various low-speed communications for emergency. However, in recent years, as satellite networks are in further development and commercialization, the LEO satellite networks are in urgent necessary of transforming its service on providing additionally efficient transmission for the high-speed and real-time multimedia applications [1].

As for satellite networks, some former researchers treat satellite network as delay and distruption tolerant networks(DTN). For example, due to the long time delay, high packet loss rate, intermittent connectivity and link distruptions for satellite networks, Carlo Caini et.al [2][3] use delay and distruption dolerant networking approach as an alternative solution for future satellite networking application. In these solution, the DTN architecture provides long-term information storage on intermediate nodes to cope with disrupted links, long delays, and intermittent connectivity. Moreover, Wei Gao, Guohong Cao, et al [4] proposes a novel approach to improve the performance of data forwarding with a short time constraint in DTNs by exploiting the transient social contact patterns, representing the transient characteristics of contact distribution, network connectivity and social community structure in DTNs. Based on those patterns, they propose appropriate forwarding metrics to improve the effectiveness of data forwarding. Wei Gao, Guohong Cao[5] also study the multicasting in delay tolerant networks from a social network perspective. In their study, the relay selections for multicast in DTN are formulated as a unified knapsack problem by exploiting node centrality and social communication structures. In addition, considering the socially selfishness of nodes, Qinghua Li, Wei Gao et al[6] propose a routing protocol for DTN. In this study, to select forwarding nodes, both user's willingness to forward and their contact opportunity are considered to derive a metric with mathematical modeling and machine learning techniques to measure the forwarding capability of the mobile nodes.

In this paper, we doesn't treat multihop LEO satellite networks as delay and disruption tolerant networks. We focus on the properties of resources in LEO networks, including the insufficient bandwidth resource of the inter-satellite links (ISLs) and the unique unbalanced load distribution features in LEO satellite networks. Those features often cause severe and dynamic link congestion, and thus have formed a critical technical obstacle for transmitting the high-speed and real-time multimedia flows, which usually impose diverse and strict delay bounds and are sensitive to the delay variations on paths [7]. First, the load of LEO network is in huge unblanced distribution. The service area of satellites cover the sparsely populated areas such as the desert or sea, as well as the densely populated areas just like the cities, forming a clustered characteristic on user distribution in network and leading to significant traffic hot spots. Second, the distribution of load in LEO network changes rapidly, which is due to the following two aspects. For one thing, the traffic intensities of different districts change over time. For another, since each satellite moves along its orbit plane and the earth rotates on its axis, the service area for an individual satellite is in rapid changing due to fast relative motion among satellites and earth. Third, the on-offs and handovers of ISLs may sometimes lead to the traffic diffusion on the surrounding links. Hence, as a comprehensive effect of these factors, the multi-hop LEO satellite network suffers the link congestion, which uccues frequently and changes rapidly. This causes fast and significant delay fluctuation on the ISLs and apparent increases the end-to-end delay of some flows and therefore reduces the quanlity of service (QoS) for delay-sensitive flows.

Therefore, in order to design routing strategy to provide good Qos for delay-sensitive flows in LEO satellite network, following two conditions should be satisfied. First, the end-to-end delay for different flows should be considered as a constraint of routing algorithm, so that the necessary condition of delay sensitive flows can be satisfied. Second, the routing strategy can adapt to the changing of congestion state of network, so that time delay constraint of different flows can be guaranteed to the most degree. However, current adaptive routing algorithms can not satisfy both of above two conditions.

Considering the traffic distribution strategy, current adaptive routing algorithms for LEO satellite network are classified into two categories. One class [9][15] divides flows in time axis and spread division units into alternative routes according to the real-time traffic distribution; the other class [10]-[14] adjusts flows to less congested alternative routes without destroying the integrity of them. The research outlined in our paper falls into the latter category.

The advantages and disadvantages of current adaptive routing algorithms for LEO netowork are analyzed as follows. [10] proposes the priority-based minimum-hop algorithm (PAR), in which packets are dispersed effectively into multiple shortest paths in mesh-like topology. Although taking multiple shortest paths for routing is a good method to satisfying end-to-end delay constraint, serious link congestion can not be avoided when network load is heavy. Some other adaptive routing algorithms [11]-[13] are based on the idea of building alternative routes for each congested link. Although the congestion can be alleviated by dispering network flow into alternative routes around congested links, these algorithms fails to satisfy the end-to-end delay constraints, when design routing paths. Moreover, such reactive schemes cause frequent QoS rerouting in a large area, which increases routing response lag and brings about heavy cost [14]. To handle this problem, [14] chooses the transmitting nodes on congested links as the initial nodes of the rerouting, so that routing response lag can be decreased. But, this mechanism fails to balance traffic in the entire constellation.

To better balance traffic in the entire constellation, an LPR routing protocol [15] is proposed recently. It transmits the link bottleneck information to all the upstream satellites, and each satellite chooses to bypass some packets to other links based on geographical location as long as the congested link is excluded. However, as the link selection and adjustment are implemented for each packet on each forwarding node by distributed hop-by-hop routing, the LPR algorithm does not keep the flow integrity, and is considered unsuitable to be extended to provide service with strict delay constraint.

Hence, above routing approaches for LEO satellite network fail to both satisfy the end-to-end delay constraint and provide good adaption to the changing of network congestion.

In this article, a novel adaptive routing algorithm is proposed to provide better QoS for delay-sensitive flows in multihop LEO satellite networks. In our scheme, the proactive DSDV routing scheme is adopted and extended to a multipath version with delay and bandwidth metrics. First, the delay on each posterior segment of routes is obtained during the routing table (RT) update, based on which a trigger condition is built on the basis of the end-to-end delay and monitored in real-time. Hence, the end-to-end delay constraint can be satisfied when designing routing paths. Second, the alternative routes are formulated actively with real-time delay metric during regular routing process, thus the fast, flexible and optimal route adjustment can be achieved to adaptive to the changing congestion state to match the end-to-end delay constraint. Moreover, a retrospective route adjustment request scheme is designed to check the alternative routes to the destination in sequence on all the nodes along the anterior path. Thus, the success rate on route adjustment in some severe congestion can be improved without loosing the efficiency in slight congestion.

The rest of this paper is organized as follows. The key philosophy and whole working scheme of DOAR algorithm is described in detail in Section 2.The performance of the algorithm is evaluated by simulation in Section 3. The paper concludes in Section 4 with a summary recapping both the advantages of the proposed algorithm and the cost for them.

2. Operational Overview of the DOAR Scheme

LEO satellite networks, such as Iridium[22] and Teledesic[23], are networks consists of satellites in low earth orbits. LEO satellite networks have following basic properties.

(1) The network topology is regular.
Most of LEO satellite networks consist of satellites that is distributed regularly in different orbits. For example, Iridium system consists of 77 satellites, which are distributed in 7 circle orbits with same radius. Each oribit has 11 satellites.

(2) Traffic loads of different satellites are in great variation.
Satellites in LEO networks are used to provide access for users on entire earth's surface. Since different satellites cover different districts with different density of population, it is inevitable that traffic loads of different satellites are in great variation.

(3) Distribution of traffic changes frequently in LEO satellite networks.
The satellites in low earth orbits moves with high velocity, thus, the cover district of each satellite changes very fast. Since different districts correspond to different densities of population, the distribution of traffic changes frequently in LEO satellite networks.

In order to provide good Qos for delay sensitive flows in LEO satellite networks, the delay-oriented adaptive routing algorithm (DOAR) is proposed in this paper. DOAR consists of three essental components. First, the alternative route generation scheme is proposed to generate multiple alternative paths for routing choice. Those alternative paths satisfy end-to-end delay constraint for different flows. Second, the delay based trigger condition are analyzed to judge whether congestion happens. Third, the route adjust requesting scheme is provided, so that routing paths for delay sensitive flows can be adjusted, when the trigger condition is satisfied. Those components of routing algorithm are listed in following subsections.

2.1 Alternative Route Generation Scheme

In the DOAR algorithm, the alternative routes are generated simultaneously in routing process as the multipath choice. It is achieved by employing the DSDV routing scheme and making some modifications to support multipath with QoS metric.

DSDV algorithm in [16] is a table-driven routing scheme based on the Bellman–Ford algorithm. In DSDV, each node maintains a local routing table (RT), which lists all the available destinations, the metric and the next hop node to each destination, and an increasing sequence number to distinguish the aging of path information. The RT is updated by the route updating packet periodically initiated by the destination nodes and the route information exchanging between neighbors. With advantages of being simple, quickly response to topology changes, no routing loops and no route discovery delay, the DSDV algorithm is in particular suitable for the small-scaled wireless mesh network, which is considered just in accordance with the LEO satellite network.

1) The DSDV algorithm supporting QoS metric

In DOAR, the DSDV is extended to support the QoS metrics of delay and residual bandwidth on paths. Let α_i^x be the route item from node i to the destination x. The distance metric of α_i^x is redefined by the path delay given by $d_i^x = d_i^j + d_j^x$, where d_i^j is the communication delay of link $e_{i,j}$ from node i to its neighbor j. Let r_i^j be the residual bandwidth on $e_{i,j}$ which is formulated by $r_i^j = c_i^j - \sum_{e_{i,j} \in p_f} \rho_f$, where c_i^j is the total link capacity on $e_{i,j}$ and ρ_f is the average rate for flow f . Then, an additional metric r_i^x , defined as the residual bandwidth to node x on node i, is attached to the route item α_i^x and can be formulated by $r_i^x = min(r_i^j, r_j^x)$.

2) The DSDV algorithm supporting multipath

The DSDV is modified to work on multipath scheme. This is achieved by extending the single route item α_i^x to a route set $\mathrm{A}_i^x = \{\alpha_i^x(k_i)\}$. k_i is the path id for $\alpha_i^x(k_i)$ in α_i^x on node i.

In order to build, update and use each route item in A_i^x, we must first be able to identify them. It is achieved by setting up a local path id pool P_{id}^i on each node i , in which each path id number $p_n^i \in P_{id}^i$, is unique on i and can only be possessed by the route item it is assigned to originally, until the route item is removed from the RT and thus its path id is released back to the pool. Thus, once a new path is received from its neighbor, a path id is chose from the remaining id number in its local path id pool and allocated to the path. And when this update packet is further forwarded to its neighbors, the parameter $< neighbor\ id, path\ id >$ is added as a signature and this new path will be recorded in the RT on neighbors coupled with this identification attribute, as shown in **Table 1**. As this continues, each path can be identified between the neighbors along it.

Table 1. Applications in each class

Dest	**Next hop**	**Local PathID**	**Neighbor PathID**	**Delay Metric**	**Res Band**	**Seq. No.**	**Install**
S1	S6	1	3	105ms	5M	S406_S6	T001_S1
S1	S6	2	4	100ms	10M	S406_S6	T002_S1
S1	S6	3	1	80ms	30M	S408_S6	T005_S1

Periodically and immediately when changes on network topology have been detected by a node, it advertises routing information by broadcasting an RT update packet. The update packet starts out with both delay metric and bandwidth metric of zero to the direct connected nodes. After receiving the update packet, the neighbors determine whether the path already in their route table. For an existing path, the neighbors update their RT by calculating the new delay and bandwidth metric using the latest link state information, modify the QoS metric and retransmit the update packet to the corresponding neighbors along the path; otherwise, they check the update packet by the multi-path reserving principle illustrated in **Fig. 1** before inserting the new path item into their RT. The update packet is propagated to the next hop neighbors only if the new path is reserved. The process will be repeated until all the nodes in the satellite network have received a copy of the update packet with corresponding QoS metrics. If a node receives multiple update packets for a path, the one with more recent sequence numbers is always preferred for representing the path attributes on QoS, but the routing information will be considered not necessarily advertised immediately, if only the sequence number has been changed. Furthermore, if the route item with updated QoS metrics has violated the multipath reserving principle, it will be discarded; and when a new path has been accepted, it might meanwhile have some other paths in the RT out of necessity according to the principle.

The path reserving principle is set on purpose of filtering out the paths that has no advantage over QoS compared to the existing paths in RT. It can be summarized to two necessary conditions as follows.

- The path in update packet must have its sequence number no κ less than the maximal sequence number of routes in A_i^x .
- The path in update packet must provide larger residual bandwidth compare to the paths that have lower delay metric than it in A_i^x .

Note that the first necessary condition provides that for each destination, the RT only keeps the paths generated in the latest κ updating process to avoid adding expired item to the RT, for the formulation of an overlong path may take too much time updating and thus has less reliable metrics. Thus, the decision for κ requires comprehensive consideration on both the variation rate of metrics and the updating cycle of paths.

```
For the update packet for route item $\alpha_j^x(k_j)$ received from neighbor $j$:
if  $Seq.No(\alpha_j^x(k_j)) \ge Max(Seq.No(\{\alpha_i^x(k_i)\})) - \kappa$ :
  if  $A_i^x = \varnothing$ :
   then generate $\alpha_j^x(k_j)$ , let $\alpha_i^x(1) = \alpha_j^x(k_j)$ , let $A_i^x = \{\alpha_i^x(1)\}$ .
  else
    $k = AscendOrder(\alpha_j^x(k_j), Delay(\{\alpha_i^x(k_i)\}), Delay(\alpha_j^x(k_j)) + d_i^j)$ .
    if $k == 1$
      then generate $\alpha_j^x(k_j)$ .
       for all $\alpha_i^x(k_i)$
         if $ResBand(\alpha_i^x(k_i)) \le min(ResBand(\alpha_j^x(k_j)), r_i^j)$ :
         then discard $\alpha_i^x(k_i)$ .
       end
    else
       if $min(ResBand(\alpha_j^x(k_j)), r_i^j) \le max(ResBand(\alpha_i^x(k_i)))$ :
         for $\alpha_j^x(k_j)$ with $k_j < k$ :
           discard $\alpha_j^x(k_j)$ .
         end
       else
          generate $\alpha_j^x(k_j)$ .
         for $\alpha_i^x(k_i)$ with $k_i > k$ :
           if $ResBand(\alpha_i^x(k_i)) \le min(ResBand(\alpha_j^x(k_j)), r_i^j)$ :
           then discard $\alpha_i^x(k_i)$ .
         end
else discard $\alpha_j^x(k_j)$ .
```

Fig. 1. The path reserving principle of the routing table

2.2 Delay-based Trigger Condition for Route Adjustment

Consider a flow set Γ transmitting in the LEO satellite network G across multi-hop paths, in which each flow $f \in \Gamma$ is supposed to be mapped into a single path p_f. A flow could be a single session or consists of a couple of sessions resembled on the access satellites according to the same destination node and the similar delay deadline. Assume a timestamp is carried in each data packet to record its experienced delay in network. Suppose node i is a forwarding node on path p_λ and x is the destination node for flow f. Let D_f^i denote the average delay in timestamps in the packets of flow f observed on node i. Let $d_i^x(p_f)$ represent the one-hop delay metric of the path p_λ on node i, which consists of the propagation delay and the queuing delay. Then, the route adjustment process for flow f on node i will be launched once (1) holds.

$$D_f^i + d_i^x(p_f) \geq \pi_f - \varepsilon_f \tag{1}$$

Where ε_f is a delay protecting margin, the optimal setting of which involves a tradeoff between two fold. With a lower ε_f, satellites can be granted a time long enough to carry out the route adjustment process and flows may take less risk on the delay deadline breakthrough. In contrast, a higher ε_f can avoid unnecessary route adjustment so as to damp the fluctuation of RT. Considering these two observations and for the sake of scheme simplicity, the ε_f is set to $\varepsilon_f = {}^{\pi_f}\!/_{4}$.

2.3 Route Adjustment Requesting Scheme

Whenever the trigger condition is satisfied on the receiving node of a congested link, a route adjusting request packet is initiated at once and transmitted to the transmitting node of the link. With proactive routing scheme, the DOAR algorithm has an inherent advantage on promoting the success probability on route adjustment by extending the node set involved in the adjustment initialization with small additional cost. Thus, a route adjustment requesting scheme is proposed, of which an instance is shown in **Fig. 2**.

When satellite A has detected that a flow f has arrived at the trigger condition, it first attempts to find available alternative route in its own RT; if it fails, it sends a Route Adjustment Request (RAR) packet to its upstream neighbor B on p_f, then B is committed to achieve the route adjustment by looking up its RT; this process continues until the route adjustment has been accomplished on an upstream node C or has been proved failed on the source node of p_f. In the former case, a Route Adjustment Confirmation (RAC) packet is generated and sent to all the downstream nodes involved in this route requesting process; and in the latter case, a Route Adjustment Failure (RAF) signaling packet will be sent. On each related node which has received a RAR packet, once a RAC packet is obtained, the RAR packet will be discarded, and if a RAF packet is received, the RAR packet will be kept for a while to await an opportunity for route adjustment.

It should be noticed that the concurrent route adjustment requesting on nodes along a path may cause fluctuation on RT and bandwidth resource waste. Thus a delaying device with two parameters, the request accepting interval τ_1 and the request reapply interval τ_2, are defined and used as follows.

- Once a node has received an RAR packet, it discards all the other RAR packets for same flow received in the next τ_1 period without entering into the route adjusting approach for it.
- Once a node has received either an RAC packet or an RAF packet, it neglects the trigger condition for same flow in the next τ_2 period to avoid inefficient route adjusting reapplication.

```
For the route set $A_i^x$ and the flow $f$ to be adjusted on node $i$,
with routing table $T_1$ and path-flow mapping table $T_2$:
Step 1: Initialize $\Lambda_i^x = A_i^x$ ; $\alpha_i^x\_alter = \varnothing$
Step 2: for all $\alpha_i^x(k_i) \in \Lambda_i^x$:
            if $ResBand(\alpha_i^x(k_i)) < \gamma_\lambda$:
            then remove $(\alpha_i^x(k_i), \Lambda_i^x)$.
        end
Step 3: for all $\alpha_i^x(k_i) \in \Lambda_i^x$:
            if $Delay(\alpha_i^x(k_i)) \geq \pi_\lambda - \varepsilon_\lambda - D_\lambda^i$ :
            then remove $(\alpha_i^x(k_i), \Lambda_i^x)$.
        end
Step 4: $K = DscendOrder(\Lambda_i^x, (r_i^x(k_i) - \gamma_\lambda))$.
        for k from 1 to $Dem(K)$:
            $k_i = K(k)$; $\alpha_i^x\_tmp = \Lambda_i^x(k_i)$.
            $d\_\varepsilon = Delta\varepsilon\_generate(d_i^x(k_i), \Gamma(\alpha_i^x(k_i)), \gamma_\lambda)$.
              for all $f_m \in \Gamma_{\alpha_i^x(k_i)}$:
                if $d_i^x(k_i) \geq \pi_{\lambda_m} - \varepsilon_{\lambda_m} - D_{\lambda_m}^i - d\_\varepsilon$:
                  then $\alpha_i^x\_alter = \alpha_i^x\_tmp$,
                  break.
              end
        end
Step 5: if $\alpha_i^x\_alter \neq \varnothing$:
        then $Modify(T_1, T_2, \alpha_i^x\_alter, f)$ .
```

Fig. 2. The routing adjusting approach of DOAR algorithm

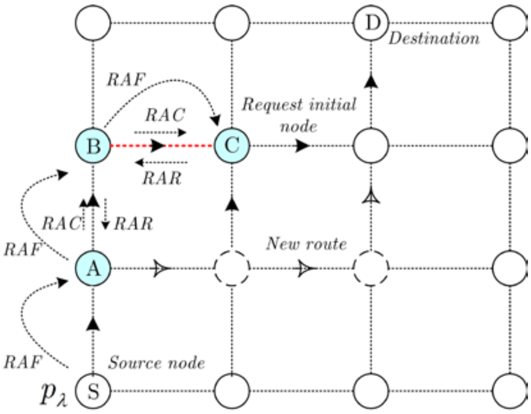


Fig. 3. An instance for route adjustment requesting scheme

The approach steps are shown in **Fig. 3**. A route adjusting approach triggered on by delay condition works on selecting an alternative route for the flow and then modifying the flow-path mapping table so as to transmit the flow via the alternative route. For a flow f destined for node x on a forwarding node $i \in p_f$, the alternative route is formulated by solving the optimization problem that

Maximize

$$r_i^x(k_i) - \gamma_f \tag{2}$$

Constraint

$$D^i_{f_m} + d_i^x(k_i) < \pi_{f_m} - \varepsilon_{f_m} - \Delta\varepsilon_f^{k_i}\text{, for } f_m \in \Gamma_{\alpha_i^x(k_i)} \tag{3}$$

$$r_i^x(k_i) - \gamma_f > 0 \tag{4}$$

$$\alpha_i^x(k_i) \in \mathrm{A}_i^x, \alpha_i^x(k_i) \neq p_f^i \tag{5}$$

$r_i^x(k_i)$ is the bandwidth metric on path $\alpha_i^x(k_i)$. γ_f is the bandwidth requirement of flow f. p_f^i is the posterior segment of p_f from node i. $\Gamma_{\alpha_i^x(k_i)}$ is the flow set on path $\alpha_i^x(k_i)$. $\Delta\varepsilon_f^{k_i}$ in (3) denotes the possible delay incremental on the target path caused by the joining of flow f. As the dynamic estimation on $\Delta\varepsilon_f^{k_i}$ requires large amount of real-time information, in DOAR, $\Delta\varepsilon_f^{k_i}$ is designed to be just as a delay guard space to avoid the chain-reacting route adjustment of other flows on $\alpha_i^x(k_i)$ and thus is evaluated by

$$\Delta\varepsilon_f^{k_i} = d_i^x(k_i) \times \frac{\gamma_f}{\sum_{f_m \in \Gamma_{\alpha_i^x(k_i)}} \gamma_{f_m}} \tag{6}$$

The efficiency of DOAR can be analyzed as follows. First, it can be found that multiple routing paths that satisfy time delay constraint are obtained in the form of routing table through alternative routing scheme. Moreover, these routing paths are updated timely according to current network topology information. Second, it can be found that the delay based trigger condition, as mentioned in (1), is very simple to be checked for each flow. Third, due to the existed alternative routing paths, once the trigger condition is satisfied on the receiving node of a congested link, route paths for flows passing through the congested link can be adjusted with high success probability and low cost.

3. Simulation and Analysis

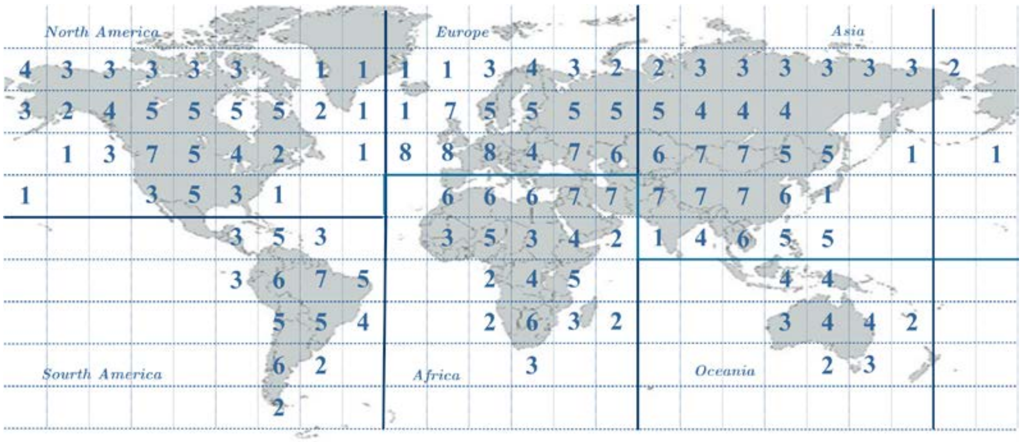
In this session some simulation results of DOAR is presented and compared to typical routing schemes in satellite networks, including some adaptive routing algorithms.

We focus on delay performance in terms of the average in-time packet deliver ratio, the delay interruption rate, and the average end-to-end delay in network. We also explore the packet dropping rate and the network throughput. These performance are presented against a variety of daily traffic, thus to test the performance of DOAR in different congestion intensity and scope.

3.1 Network Topology and Traffic Model

A Low-Earth Orbit (LEO) walker constellation with 7×9 satellites in 1400km is adopted in simulation. Every satellite has four ISLs and keeps handover to its nearest neighbors along with the movement of satellites. For simplicity, all ISLs are assumed to be identical in capacity which is assumed to be 0.32Gbps. Each ISL has a buffer size 60Mbytes. As a packet size l_{packet} is assumed to be 1Kbytes, the buffer size is set to be 60000 packets, which is 1.5 times of the ISL capacity.

The traffic model in [10] is adopted in our simulation. It depends on the 2005 statistics about the user density levels per zone as shown in **Fig. 4**, the internet host density levels per continent as in **Table 2**, and user activity levels per hour in percentage of the daily total traffic as in **Fig. 5**.



Intensity level	1	2	3	4	5	6	7	8
Traffic(million minutes per year)	1.6	6.4	16	32	95	191	239	318

Fig. 4. The continent and regional division for flow generation and the intensity level for each zone [17]

Table 2. Internet host distribution by continent [18] (January 2005)

Continent	Number of Hosts ($\times 10^3$)	Continent	Number of Hosts ($\times 10^3$)
North America	223545,1	***South America***	6026,2
Europe	52947,1	***Africa***	5621,6
Asia	28511,4	***Oceania***	671,3

Suppose each two zones with intensity level in **Fig. 4** have bi-directional flows between them. For the flow f_{ab}^{cd} from any source zone Z_{ab} and Z_{cd} in **Fig. 4**, the arrival of the packet is supposed to be a Poisson process with the average rate $\lambda(ab,cd)$ (bps) generated as in [10] by

$$\lambda(ab,cd)=\frac{T(ab,cd)}{\sum\limits_{\forall Z_{ab}}\sum\limits_{\forall Z_{cd}}T(ab,cd)}\times\alpha_{ab}\times\frac{A}{3600}\times l_{packet} \tag{7}$$

Where A is the total traffic generated worldwide per day (bps), α_{ab} is the user activity level in current time in the Z_{ab}, and $T(ab,cd)$ is the supposed traffic requirement for the flow f_{ab}^{cd}, which decides the comparative percentage of traffic occupation of the f_{ab}^{cd} in total traffic. Let u_{ab} be the user intensity level of the zone Z_{ab} and let h_{cd} be the host intensity level of the zone Z_{cd}, which is defined as the proportion of the total host intensity of the continent C_{ab} it belongs (as shown in **Fig. 4**) according to the proportion of its user intensity as in (8).

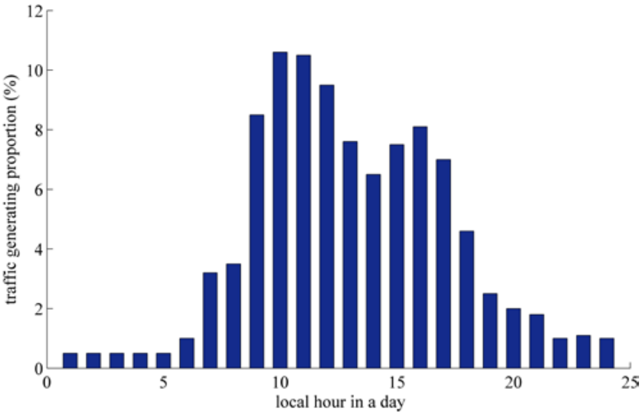


Fig. 5. User activity percentage per hour in a day [19]

$$h_{ab}=h_{C_{ab}}\times\frac{u_{ab}}{\sum\limits_{Z_{ab}\in C_{ab}}u_{ab}} \tag{8}$$

Let $L(ab,cd)$ denote the distance between the region Z_{ab} and Z_{cd}, then according to the traffic generating method in [19], the $T(ab,cd)$ can be given by

$$T(ab,cd)=\frac{(u_{ab}h_{cd})^{\theta}}{(L(ab,cd))^{\psi}} \tag{9}$$

Note that in our simulation, we choose $\theta=0.5$ and $\psi=1.5$ as in [10] [13].

Based on the above traffic generating model, we generate a total flow set for each two zones with positive user intensity level and host intensity level, forming the traffic flowing with their percentage among continents as shown in **Table 3**, in which it is obviously that the traffic transmitting demand shows the characteristic of unbalanced distribution. Each flow is assigned a delay deadline chosen from the delay constraint set $[0.2s,0.4s,1s]$ in sequence.

Table 3. The traffic transmission percentage among continents

	North America	Europe	Asia	South America	Africa	Oceania
North America	84.1%	7.2%	5.7%	1.8%	0.7%	0.5 %
Europe	32.7%	46.2%	15.9%	1.7%	1.1%	2.4%
Asia	30.4%	18.6%	44.5%	1.5%	3.5%	1.5%
South America	52.3%	11.6%	8.5%	24.0%	1.9%	1.7%
Africa	32.5%	10.7%	28.7%	2.7%	24.9%	1.5%
Oceania	32.7%	35.6%	18.8%	3.8%	2.3%	6.8%

3.2 Simulation Result

The simulation is formulated based on the network and traffic model given above. The routing algorithms involved in the simulation include:

- The Minimum-hop routing algorithm (MHA) [21].
- The ePAR adaptive routing algorithm [10].
- The B-LBAR adaptive routing algorithm; it is built as a simplified version of the bandwidth-based local balancing adaptive routing, in which alternative route is built between the transmitting node of congested links and the first-arrived node on the original posterior path with constraint that the residual bandwidth of which is no less than 25% link capacity.
- The DOAR adaptive routing algorithm, as proposed in this paper.

Note that the MHA algorithm is used as the initial routing algorithm by the B-LBAR algorithm and the DOAR algorithm, thus to test their path adjustment ability in congestion state.

The total simulation time is 24 hours. Flows are generated in cycle type with each has a staggered initial time and a same duration time of 20min, thus, the performance is tested in a dynamic flow generation process.

1) Drop ratio and throughput

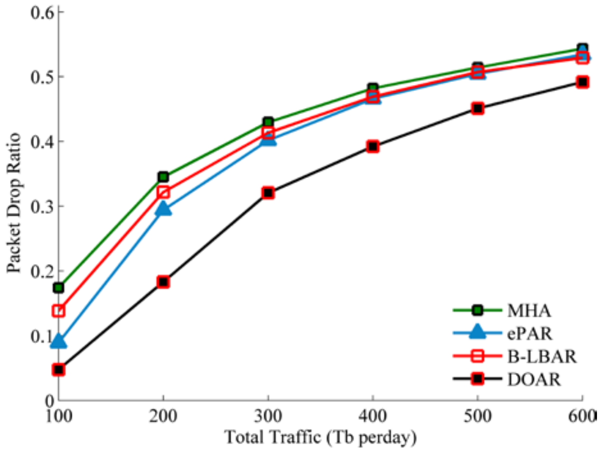


Fig. 6. Drop Ratio versus Traffic Intensity (Tb perday)

The simulation results for packet drop ratio versus daily traffic intensity of different routing algorithms are presented in **Fig. 6.** It can be seen from simulation that, DOAR obtains minimum packet drop ratio among different routing algorithms. As for other algorithms, MHA performs the worst, since network congestion can easily happens, if each flow is routed through single minimum jump path. The ePAR algorithm performs better than MHA, since additional shortest paths for each flow can be used to balance network load. The B-LBAR algorithm gets the drop ratio between the MHA algorithm and the ePAR algorithm. It might because the link congestion in a relatively large region reduces the success rate of local route adjustment, especially for the bottleneck links in the core congestion area. Moreover, if traffic load is heavier than 400Tbps, which caused congestion with larger intensity and wider scope, the route adjusting schemes in the ePAR algorithm and B-LBAR algorithm almost lose their effects, while DOAR still works well. Notice that, when traffic intensity is larger than 200, and less than 400, the advantage of DOAR is more obvious than the situation when traffic intensity lies in other interval. It is because, when traffic intensity is larger than 200, and less than 400, the network still has spare links resource for dispersing network load of some congested links. However, when traffic intensity is larger than 400, such effect is weakened. Since, when traffic intensity is larger, the number of congested links increases, and less spare links resources can be used for dispersing network load.

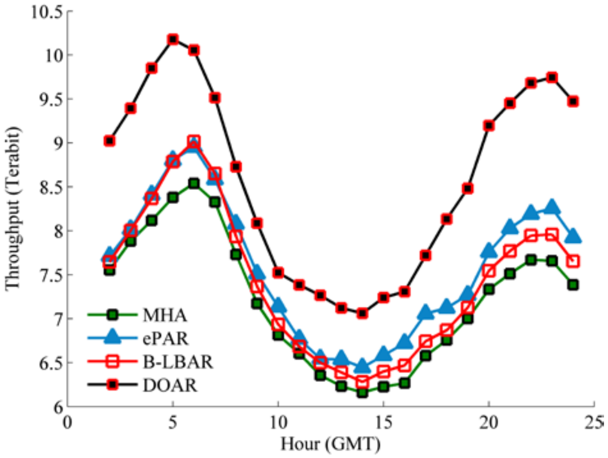


Fig. 7. Successfully Transmitted Data (Tb) versus Hour (GMT)

The throughput performance of different algorithms in each hour is illustrated in **Fig. 7**, where the x axis indicates different hour, and y axis indicates the successful transmitted data per hour (in Terabits), when A = 300Tbps. It can be seen that DOAR obtains largest throughput, among all four algorithms, in each hour. Moreover, the routing algorithms show different throughput performance during the traffic distribution changing in a day. Notice that two peaks correspond to the time when user activities are in peak levels in Europe and Northern America respectively.

2) Delay performance

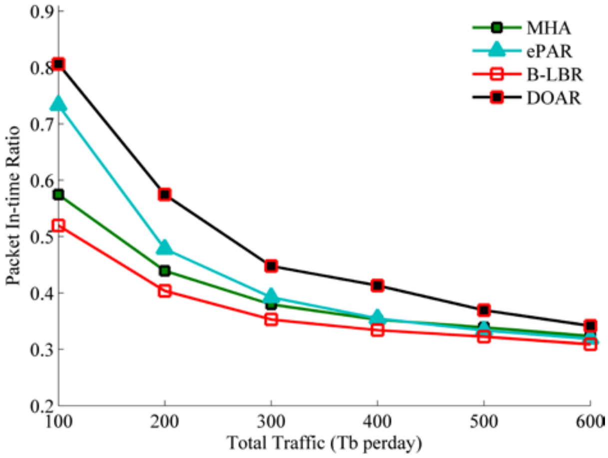


Fig. 8. Packet In-time Ratio versus Traffic Intensity (Tb perday)

Delay performance of different algorithms is presented in **Fig. 8-10**. **Fig. 8** illustrates packet in-time ratio of different algorithms, which is defined as the proportion of packets whose values of end-to-end delay are kept in its own constraint in the total receiving packets. It can be seen from **Fig. 8** that the DOAR algorithm achieves maximum packet in-time ratio, among four algorithms, in different traffic intensity. It is because that DOAR obtains more balanced traffic distribution and can better adjust route when congestion happens, than other algorithms do. As for other algorithms, ePAR obtains larger packet In-time ratio than MHA, since alternative shortest paths for each flow are used to disperse network load when congestion happens. Moreover, it can be observed that the B-LBAR algorithm performs the worst. This is caused by the poor end-to-end delay performance which can be found in **Fig. 9** and **Fig. 10**.

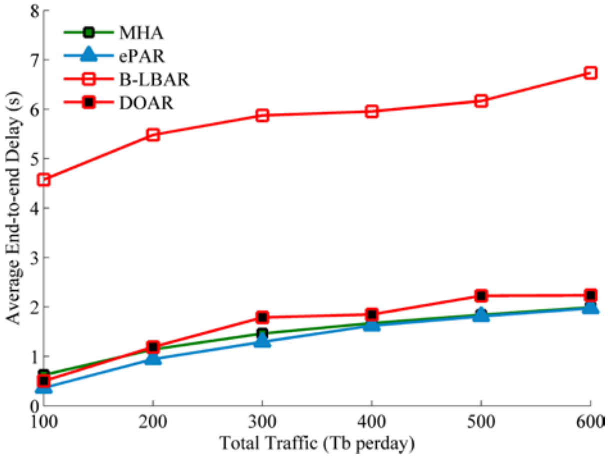


Fig. 9. Average Delay (s) in a Day versus Traffic Intensity (Tb perday)

The average end-to-end delay for flows in a day is shown in the **Fig. 9**. It can be seen that the MHA, ePAR and DOAR algorithms have similar end-to-end delay when the daily traffic is less than 200. When the traffic intensity is higher, the end-to-end delay of DOAR algorithm is a little larger than that of MHA and ePAR algorithms. A remarkable result is that the B-LBAR algorithm gets its delay much higher than the others. Both the results of DOAR and B-LBAR confirm what we have expected that in a severe congestion state in a large area with changing traffic distribution, route adjustment may expand the total congested region and result in the growth of the queuing delay on paths. The DOAR algorithm reduces this defect by increasing the route adjusting range and reducing the path hops increase; while on the contrary, the B-LBAR algorithm has an obvious local feature in route adjustment and makes significant growth on the hop number of paths, leading to longer queuing delay and propagation delay.

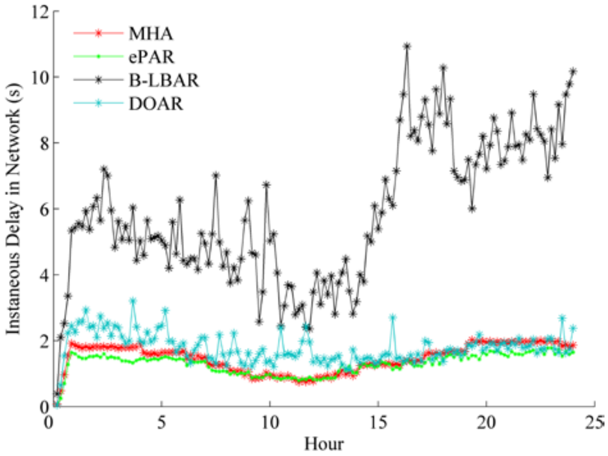


Fig. 10. Instantaneous Delay (s) in network versus Hour (GMT) at the Traffic Intensity 300Tb per day

Fig. 10 illustrates the instantaneous delay in network versus Hour (GMT) for different algorithm when traffic intensity is set to be 300T bits per day. It can be seen that instantaneous delay of DOAR changes more frequently than that of MHA and ePAR. It is because the routing paths for different flows are set to be shortest paths from sender nodes to destination nodes, under MHA and ePAR algorithm, while DOAR has more alternative paths with different end-to-end delay for routing adjustment when congestion happens. As for B-LBAR algorithm, although routing paths can be adjusted when congestion happens, the end-to-end delay is much higher than that of other algorithms. Since B-LBAR doesn't sufficiently consider the end-to-end delay constraint, which leads to poor delay performance, although route can be adjusted when congestion happens.

4. Conclusion and Future work

In this paper, a new adaptive routing algorithm is proposed. It designs a route adjusting scheme for delay-sensitive flows in the uninformed and time-varying traffic distribution in LEO satellite network. Simulation result shows the performance improvement, and furthers more, illustrates that the DORA algorithm is effective especially in the severe congestion states on ISLs caused by heavy traffic intensity. In addition, different from current schemes, the cost of the DORA algorithm mainly depends on the network size rather than the route adjusting request numbers, which means that it might be more suitable for small scale network.

Furthermore, the DORA algorithm is considered might also be effective on reducing the call blocking rate and handover blocking rate by appropriate route adjustment on transmitting flows. And furthermore, in some traffic model in satellite networks, a large portion of users intends to transmit data to the terrestrial network via the ground stations. This may reduce the cost for route updating in the DORA algorithm and make capacity and QoS improvement by providing flexible traffic balance among sink nodes. These suppositions will be test in the future work.

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