



A Dynamic Modified Routing Strategy Based on Load Balancing in LEO Satellite Network

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Abstract. A dynamically modified load balancing routing strategy, named Dynamic Modified routing table based on Load Balance (DMLB) was proposed in this manuscript for the problem of congestion and packet loss, which was caused by uneven distribution of business traffic in the low earth orbit (LEO) satellite network. Different from the traditional routing protocol for the satellite, the strategy forms a kind of fast forwarding through the steps of geographical location-based traffic prediction, calculation of the entire network routing forwarding table based on weighted shortest path and dynamic correction of load balancing based on priority. These lead to an efficiently updated routing protocol. Simulation results show that the proposed DMLB strategy has better load balancing capabilities and smaller rerouting convergence time, ensuring the reliability of delay-sensitive service transmission, reducing link management overheads, and saving on-board computing resources.

Keywords: LEO network · Routing strategy · Dynamic-static combination algorithm · Load balancing

1 Introduction

With the growth of various types of communication services, terrestrial communication networks have been unable to meet the exploding traffic demands. Satellite network have broken the limitations of traditional geographical environment and can provide Internet access services for any users in the world [1]. The features that low transmission delay and small size of user terminals have become a new direction for the development of communications infrastructure in the future [2]. In April 2020, satellite Internet was included in the list of “New Infrastructure Construction” by China and has broad development prospects [3].

Satellite network is a part of the Internet based on satellite communications. By deploying a certain number of satellites in space to provide broadband Internet access services for ground or air users, the development of this system began in the 1980s, based on “Iridium” constellation supported by Motorola. Recently, companies such as

SpaceX and Amazon have begun to lead the construction of new satellite constellations [4]. In June 2020, the ninth part of Starlink was finished and the number of satellites in orbit reached to 540. Encouraged by relevant policies, China has launched a number of LEO satellite constellation plans since 2017. Constellations represented by Hongyun, Hongyan and Xingyun have successively launched demo satellites.

As a key technique to enable worldwide service, the routing protocol have been attracted much attentions. Scholars [5] proposed a method to reduce the frequent switching of network connections for LEO satellite constellations. But they restrict more high-priority services and affect the QoS service quality. Scholars [6–8] proposed Many typical methods of load-balancing routing protocol. One of them called LBRD for satellite networks based on geographic location as a routing strategy using neighbor notification to adjust the load. This method effectively reduces the delay caused by congestion and data packet loss rate. The traffic in the network needs to be recalculated every time according to the demand, so the resource consumption is large and there is no relatively fixed routing table, which affects the communication efficiency. Scholars [9] proposed a route update method based on source route multicast for the problem of topology changes in the snapshot route in the software-defined network architecture. This method can avoid loops generated during the satellite network update process, reduce the convergence time and network overhead. But when a link is suddenly congested or malfunctions, the packet loss rate increases significantly. Scholars [10] proposed an improved algorithm based on the traditional routing protocol OSPF for the problem of the cost and stability of the intra-domain routing protocol in the integrated network of heaven and earth. This algorithm introduces the topology prediction function, which combined with the neighbor state, reducing the flooding and calculation overhead and improving in order to stabilize the operation. The convergence is completed quickly. However, when the topology changes, the entire network still needs to be calculated. There is a problem of packet loss during convergence and no load balancing method is involved. Scholars [11, 12] proposed new network architectures, communication protocols and evaluation methods for mobile ad hoc networks, and scholars [13–15] gave better load balancing strategies for dynamic resource allocation, especially access links. Scholars [16, 17] apply deep reinforcement learning to the resource allocation of satellite communications, explore the relevance of different time slices, convert the system state into pictures, extract features, and then identify and make decisions.

Aiming at the problem of load balancing in LEO satellite network, this paper proposes a dynamically modified load balancing routing strategy. This strategy predicts the traffic distribution in advance according to the distribution of ground users, and fits the traffic distribution to the link weights. The weighted link weights are used to calculate the optimal path. The priority is used as the goal to interact with the neighbor status information. The load is adjusted, and the routing table is dynamically modified to ensure that subsequent packet forwarding can inherit the current optimal state. When the link state is congested again, the previous steps are looped to form a fast query, efficient update dynamic and static combined route protocol.

The rest of the paper is organized as follows: Sect. 2 describes the system model for LEO satellite network. Section 3 presents the dynamically modified load balancing

routing strategy. Section 4 describes the simulation parameters and results analysis. Section 5 concludes the paper.

2 System Model

The LEO satellite network system is mainly composed of three parts: satellite, ground station and user terminal. The user terminal initiates the Internet access request and reaches the ground station through the inter-satellite link between the satellites. The ground station serves as a gateway to access the Internet. When transmitting service information to the user through the inter-satellite link the two user terminals serve as a group, by which users can communicate with each other. The routing strategy provides services for the path selection of IP data packets between the satellites. The data packets are transmitted hop-by-hop between the satellites by querying the next hop port from the source to the destination. The routing strategy plays an important role in the reliability of data transmission. Figure 1 shows the working principle of the system.

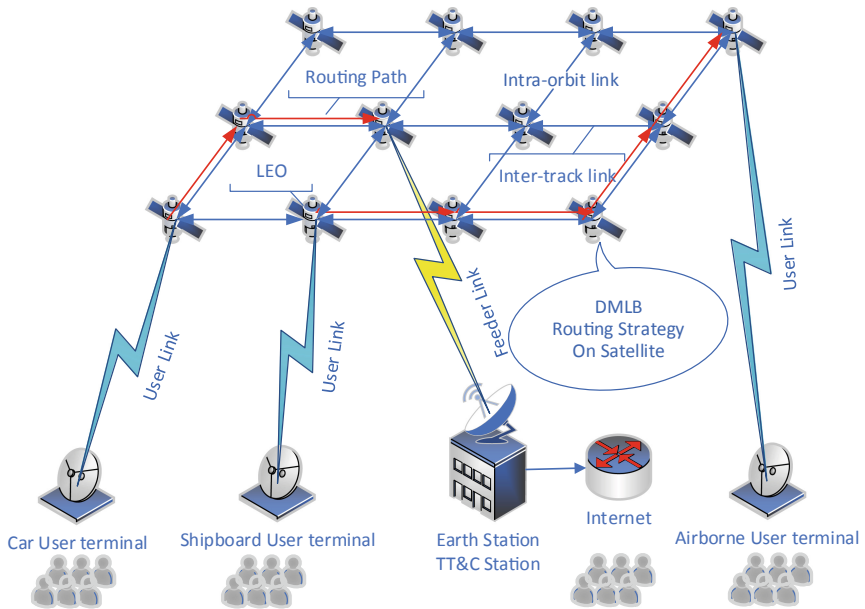


Fig. 1. Architecture of LEO satellite network

In LEO satellite network, the relationship between neighbors is relatively fixed with distributed topology and periodic inter-satellite links. But the distribution of ground users is uneven, and the distribution of business traffic is uneven, which is likely to cause traffic bursts. The resulting congestion and packet loss, while the surrounding network is not fully utilized. If the static time slice routing strategy is used on the satellite, the network will not be able to cope with the emergency situation. If the common dynamic routing strategy is adopted on the satellite, a large amount of link resources will be consumed

when the network status is updated, and it will also be A large number of packets are lost and the re-routing time is long. If the self-organized load balancing route is adopted, although it can deal with burst traffic, for the scenario of simultaneous communication between multiple nodes, it will consume a lot of on-board computing resources and Produce a large delay.

3 Dynamically Modified Load Balancing Routing Strategy

This routing strategy is aimed at LEO satellite network and is used in a single-layer LEO satellite constellation that can be globally covered. A user link is established between the satellite and a number of ground stations, data transmission is performed between the satellite and the satellite through an inter-satellite link, and a feeder link is established between the satellite and the gateway station. The gateway station can be connected to the ground Internet. Therefore, the network can provide services for users to access the Internet or for direct communication between users and users.

Among them, the most critical is how to optimally select the path to ensure the reliability of communication. This section will explain in detail the steps of the execution of the routing strategy.

3.1 Geographical Traffic Forecast

Supposing that the number of constellation orbits is M, the number of satellites in each orbital surface is N, V_{ij} represents the j satellite in the i orbit, and the inter-satellite link between the satellites V_{ij} and V_{i+1j} is represented as $E_{ij,i+1j}$, The number of user stations accessing the satellite V_{ij} is U_{ij} , then the total number of satellites $M * N$ [18], and the total number of ground user stations are:

$$U_{max} = \sum_{\substack{0 < i \leq M \\ 0 < j \leq N}} U_{ij}, i, j, M, N \in N$$

In the initial state, the flow prediction value F_{ij} of each satellite node is established and the mapping relationship between the number of user stations U_{ij} is established:

$$F_{ij} = \sum_{t=0}^{U_{max}} k_f * f(u_t)$$

Where u_t is a specific user in U_{ij} , k_f is a predictive adjustment factor, and the node traffic prediction value is adjusted according to the user level and the type of transmission service. Generally it can be divided into 16 levels, with values ranging from 0 to 15. The distribution of users in different geographic locations is different. At the initial moment, each user station u_{ij} reports the area location information, user level, and service type waiting to be transmitted to the visible star with the longest connection time. The satellite obtains the traffic prediction value F_{ij} (Fig. 2).

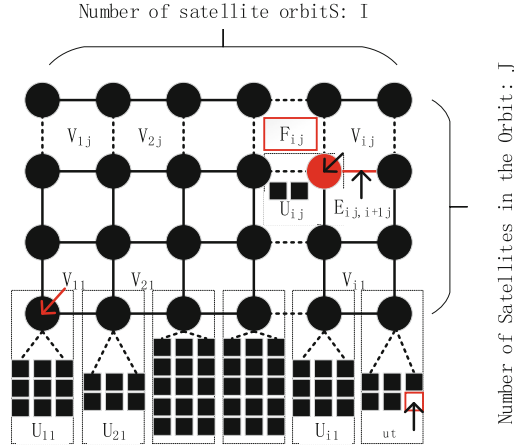


Fig. 2. Model of network topology

3.2 Calculation of the Weighted Shortest Path of the Entire Network Routing Forwarding Table

At the initial moment, in a $M * N$ -scale network, satellite V_{ij} establishes 4 duplex links between common and different orbits, while the first orbit and the last orbit I do not establish a different orbit chain due to the opposite movement direction Road, so the total number of inter-satellite links is:

$$E_{max} = \frac{4 * M * N - 2 * N}{2} = (2M - 1) * N$$

Each link is divided into two channels, and each channel is equivalent to a directional edge. The weight W of the channel is proportional to the satellite traffic prediction value F_{ij} , the scale factor is k_w , and the weight of the directional edges V_{ij} to V_{st} is:

$$W_{ij,st} = k_w * F_{ij} = k_w * \sum_{t=0}^{Umax} k_f * f(u_t)$$

At the next moment, the satellite V_{ij} sends the obtained weight $\{W_{ij,i\pm 1j\pm 1}\}$ to the neighbor set $\{V_{i\pm 1j\pm 1}\}$, and obtains the directed edge weight of the neighbor set, add weights to the local matrix M_d , the matrix format is as follows (Fig. 3):

At the next moment, it is sent to the neighbor set $\{V_{i\pm 1j\pm 1}\}$ to continue to help V_{ij} diffuse its weights $\{W_{ij,i\pm 1j\pm 1}\}$, and at the same time V_{ij} receives and updates the weight table, after the time $M + N$, the satellite V_{MN} receives the link weight information of the satellite V_{11} , and the weight status of the entire network is unified.

At this time, according to the weight table and the Freud algorithm, the shortest path table between the stars is calculated, and the forwarding port is stored in the routing table. The path calculation continues through all satellite nodes in the order of the arrow, that is, when the satellite V_{ij} is the routing forwarding point, the calculation The weight sum of any two non-adjacent satellites is written into the shortest path table $\{D_{ij}\}$. At the

$$\begin{matrix}
 M_d & V_{11} & V_{12} & V_{13} & \cdots & V_{i-1j} & \cdots & \cdots & V_{ij} & \cdots & \cdots & V_{i+1j} & \cdots & V_{MN} \\
 V_{11} & 0 & W_{11,12} & 0 & & & & & & & & & & 0 \\
 V_{12} & W_{12,11} & 0 & W_{12,13} & & & & & & & & & & 0 \\
 V_{13} & 0 & W_{13,12} & 0 & & & & & & & & & & 0 \\
 \vdots & & & & \ddots & & & & & & & & & \vdots \\
 V_{i-1j} & & & & & 0 & & & W_{i-1j,ij} & & & & & 0 \\
 \vdots & & & & & & \ddots & & \vdots & & & & & \vdots \\
 \vdots & & & & & & & & W_{ij-1,ij} & & & & & \vdots \\
 V_{ij} & & & & & & & & W_{ij,i+1j} \cdots W_{ij,i+1j} & & & & & 0 \\
 \vdots & & & & & & & & W_{ij+1,ij} & \ddots & & & & \vdots \\
 \vdots & & & & & & & & \vdots & & \ddots & & & \vdots \\
 V_{i+1j} & & & & & & & & W_{i+1j,ij} & & & 0 & & 0 \\
 \vdots & & & & & & & & & & & & \ddots & \cdots \\
 V_{MN} & 0 & 0 & 0 & \cdots & 0 & \cdots & \cdots & 0 & \cdots & \cdots & 0 & \cdots & 0
 \end{matrix}$$

Fig. 3. Inter-satellite link weight storage matrix M_d

beginning, the weight sum is ∞ . After iterative calculation, the weight table converges and forms Forwarding table $\{R_{ij}\}$. The definition of the forwarding table is: If the shortest path between V_{ij} and V_{st} is forwarded via V_{ij} 's PO port, then in V_{ij} , port PO is included in the next hop of the packet's destination as V_{st} , that is, when the packet is sent to V_{st} via V_{ij} . At the time, after looking up the table, forward directly through PO (Fig. 4).

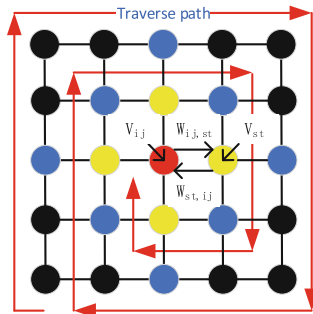


Fig. 4. Schematic diagram of satellite link weights and calculation traversal paths

3.3 Priority Load Balancing Dynamic Correction

After the routing status of the entire network is unified, IP data packets will be forwarded according to the routing table $\{R_{ij}\}$. As traffic increases, neighbor queues will be congested. Neighbor queues can be divided into $2N$ according to QoS level, and the average time per queue is \bar{q}_l , l is the corresponding rank queue number, $f(l)$ is the

weight of the queue, and the maximum capacity of each queue is Q_{max} , then the load rate of the link in this direction is:

$$L_{ij,st} = \sum_{l=1}^{2^N} [f(l) * \bar{q}_l] / \left[\sum_{l=1}^{2^N} f(l) \right] * Q_{max}$$

If the load rate exceeds L_g or the single queue exceeds \bar{q}_g , it is considered that the path is congested. At this time, dynamic routing addressing is started, that is, the load rate L of other adjacent satellites is compared, and the smaller one is selected as the next-hop routing port. The local routing table is revised immediately, and subsequent IP data packets are forwarded according to the revised routing table until the next congestion occurs, and the above steps are recycled. At the same time, in order to avoid loops, it is forbidden to send data packets back to the sending port (Fig. 5).

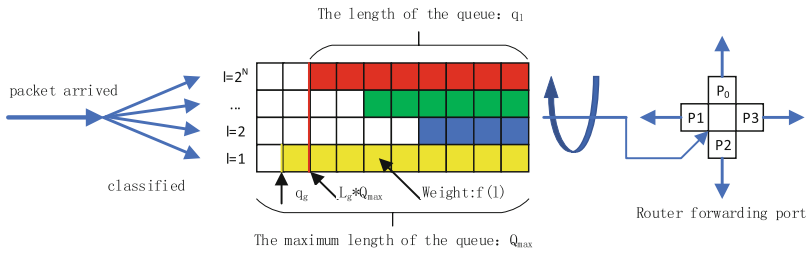


Fig. 5. Schematic diagram of Queue weighting and forwarding process.

4 Performance Analysis

Performance analysis adopts the network simulator EXata, which is developed by Scalable Networks Technologies of the United States. The simulation scenario is set according to the parameters of the low earth orbit constellation, including the global distribution of data streams, ground user terminals and gateway stations [19]. Three typical routing strategies, the static routing, OSPF and LBRD, are compared with the proposed DMLB routing strategy. Packet loss rate, rerouting time, throughput and average end-to-end delay are compared.

4.1 Simulation Platform

EXata standardized network simulator is selected as the simulation platform, where main functional modules are listed as Table 1.

Table 1. Composition and suppliers of simulation platforms

Functional module	Software	Company
Display control platform	Simulation testbed	ISCAS
Simulation engine	EXata 5.1	Scalable Networks Technologies
Development Platform	Visual Studio2010	Microsoft

4.2 Constellation Parameters and Scenario Settings

See Table 2 and Fig. 6.

Table 2. The parameters of LEO constellation, user station and link

Item	Parameter	Item	Parameter
Mobility model	Body2-orbit	User terminal	200
Number of satellites	108	Earth station	10
Number of orbital planes	9	Channel bandwidth	10 Mbps
Satellites in orbit	12	Applications	CBR
Track type	Near polar orbit	Data flow	1–10 Mbps
Inclination	86°	Packet size	2048 bytes
Constellation	Walker	Number of queues	3
Phase factor	4.5	Cache size	150000 bytes
Earth radius	6371 km	Queue scheduling	FIFO
Height of orbital planes	1000 km	Simulation time	60 s

4.3 Simulation results

(1) Packets loss rate due to link failure.

At the initial moment, each routing strategy has been configured and converged. At $t = 20$ s, a fault breakpoint is set in each forwarding link, and the packet loss rate is monitored. The static route cannot update the configuration information. It can only be forwarded along the original path, so the failure rate continues to increase. OSPF uses Hello packets to detect the status of neighbors. When a fault is detected, the entire network is updated. During the update, data packets are lost. After 27 s, the routing is

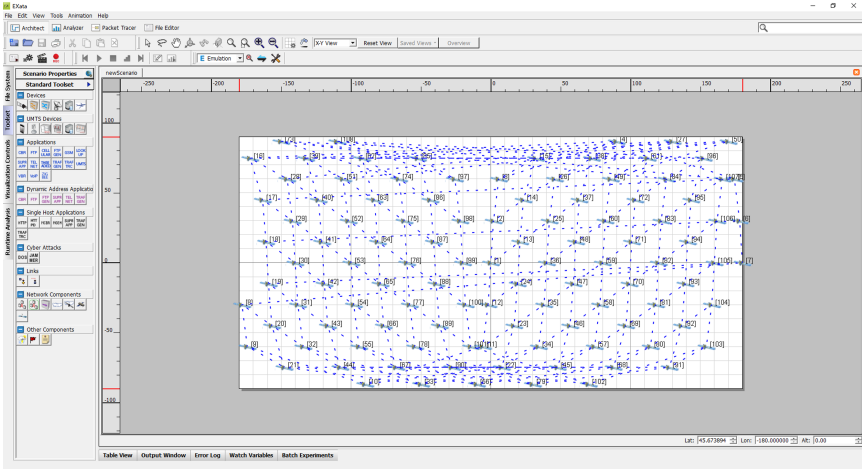


Fig. 6. Scenario topology diagram in EXata

updated and the packet loss rate decreases rapidly. LBRD only calculates the remaining paths after a link failure, so the path calculation is completed at 10 s, and the packet loss rate gradually decreases. From the simulation results, it can be seen that the packet loss rate of DMLB when the link fails has almost no obvious change. The reason is that after detecting the link failure, the satellite node starts dynamic calculation and only corrects the next hop, that is It can avoid the impact caused by link failure, and at the same time, replace the newly generated forwarding path with the original one to ensure that subsequent data can be forwarded in time after the arrival of subsequent data (Fig. 7).

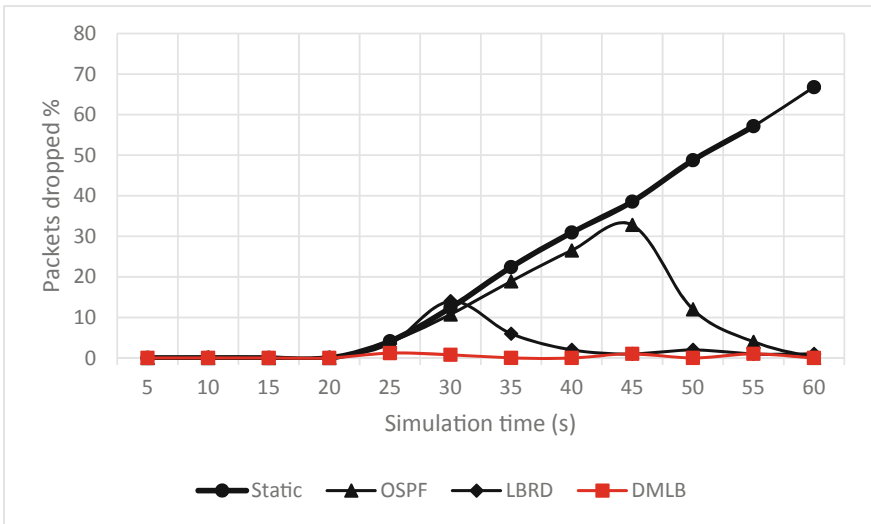


Fig. 7. Packets dropped rate

(2) Destination node throughput during link congestion.

The source and destination of the service are set according to the user station and the gateway station respectively. And then, specify the transmission path for testing. The total send traffic of the source increases from 1 Mbps to 10 Mbps. At this time, the link bandwidth limit is reached. As the amount of data sent increases, the data throughput received by the destination Also increased, but static routes have congested some links after exceeding 6Mbps. Because there is no adjustment mechanism, saturation occurs. After congestion occurs in OSPF, the link is disconnected after some queues on some ports overflow, and OSPF recalculates After that, the flow has increased. LBRD and DMLB increase with traffic, because the load balancing strategy is adopted to improve the forwarding capacity, so the throughput also increases accordingly (Fig. 8).

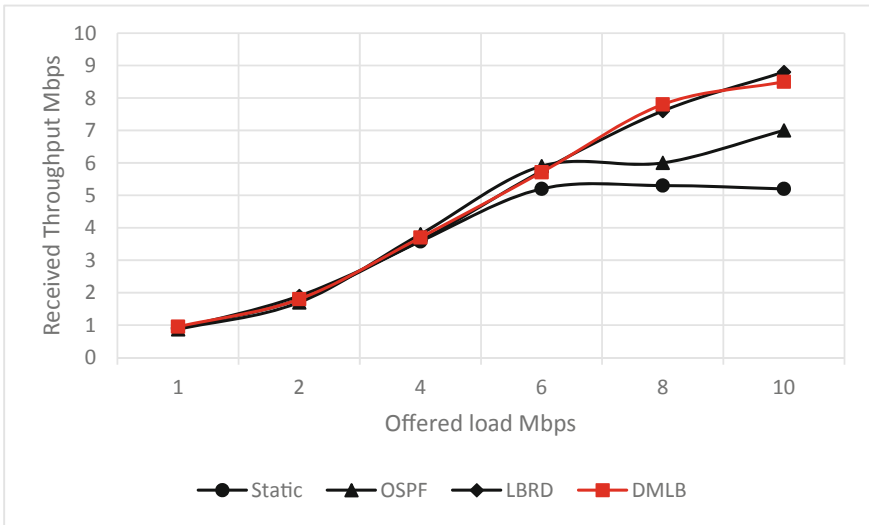


Fig. 8. Received throughput

(3) Average end-to-end delay when the link is congested.

The end-to-end delay is mainly composed of inherent path delay, information processing delay and queue waiting delay. The main impact on the delay in this simulation is mainly the queue waiting delay. When the amount of data increases, due to Static routing cannot switch to the next-hop port, so the delay increases, and OSPF will recalculate after a link problem occurs during the process. Therefore, the delay will be significantly jitter. LBRD routing uses real-time calculation, so this method is inherent The delay is greater than other strategies. As the traffic increases, due to the use of load balancing routing, the end-to-end delay increases slowly. The end-to-end delay of DMLB remains at a low value. When congestion is encountered, only The optimal choice for the next hop does not excessively change the original optimal path, so the delay is not increased.

At the same time, the queue adjustment mechanism in DMLB can reduce the delay caused by queuing. Therefore, as the amount of transmission from the source increases, DMLB Not particularly significant increase (Fig. 9).

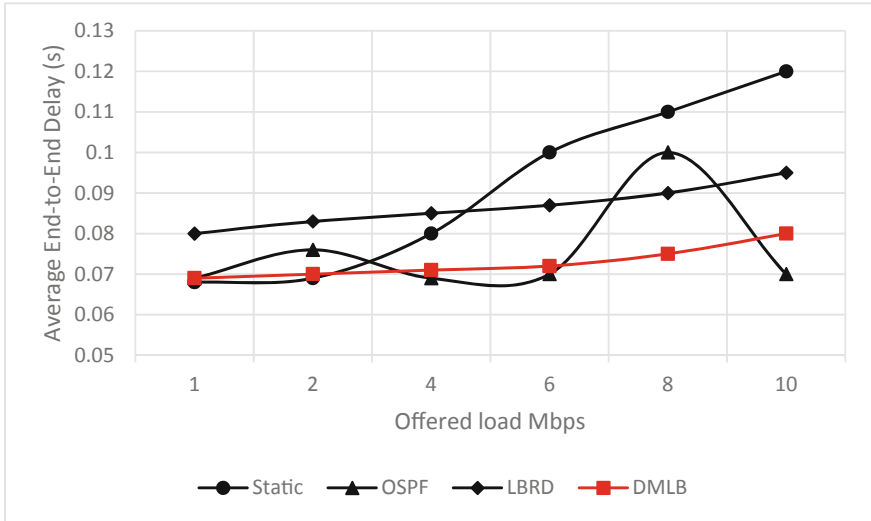


Fig. 9. Average end-to-end delay

5 Conclusion

This paper proposes a dynamically modified load balancing routing strategy for the low-orbit satellite Internet. This strategy uses traffic prediction based on the geographic location of the client, uses the weighted path length for calculation, and dynamically performs load balancing based on priority. Simulation results show that this strategy can be quickly and dynamically corrected to reduce the rerouting time and reduce the packet loss rate in case the link fails. What's more, the proposed DMLB routing strategy can ensure greater throughput and shorter end-to-end delay under the scenario of link congestion.

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