Link Attributes Based Multi-service Routing for Software-Defined Satellite Networks

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Abstract. Satellite networks are the potential complementary of terrestrial networks, which are expected to provide full-coverage and broadband access anywhere, anytime. As satellite networks scale up, Software-Defined Satellite Network (SDSN) is a promising paradigm due to its higher flexibility in network management. However, in the SDSN with highly time-varying characteristics, the traditional terrestrial routing strategy can hardly meet the QoS requirements for diverse services. In this paper, we propose a Link-Attributes-based multi-service On-Demand Routing (LAODR) algorithm under SDSN architecture. It quantifies the reliability of the Inter-Satellite Links (ISL) and provides a fine-grained state description of the dynamic topology. Furthermore, we select the K-shortest path as the solution space and reasonably allocate link resources based on LAODR to meet the diverse service demands of users. We implement LAODR and conduct experiments by using real network topologies. The results validate that LAODR not only satisfies the QoS requirements of different types of services but also outperforms other routing algorithms in terms of mean end-to-end latency, packet loss ratio, throughput and node congestion degree.

Keywords: Software-Defined Satellite Network · Link attributes · Multi-service routing · Reliable routing

1 Introduction

As the world welcomes its 8 billion inhabitants, the Internet is penetrating people's daily lives [1]. Despite the convenience the Internet offers, 34% of the global population still does not have access to it, particularly those in remote or disadvantaged areas [2]. Clearly, global coverage cannot be solved by terrestrial networks alone. Fortunately, satellite communication is an ideal long-distance communication technology with wide coverage, low affect by terrain, landscape, and natural disasters. Satellite networks, which are the convergence of satellite communication and Internet technology, are expected to be a high-capacity transmission solution providing seamless global coverage. They can not only improve ubiquitous access to global networks, but also respond quickly to emergency communication needs. How to efficiently exploit their potential for applications becomes an important issue.

To ensure reliable communication, satellite network routing design is a fundamental technology. The traditional offline routing algorithms lack the dynamic self-adaptive

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capability for satellite networks. As the satellite network expands and the ISLs become increasingly intricate, the restrictions of these algorithms become increasingly apparent. By obtaining the state information of satellite networks, it is possible to design dynamic routing strategies that are suitable for network topology changes. But the frequent signaling exchanges between satellites are likely to cause additional network burdens. Furthermore, the range of service types in satellite networks creates different Quality of Service (QoS) requirements. To efficiently utilize the limited resources on board, it also poses challenges for multi-QoS routing design [3, 4] in satellite networks.

In traditional satellite distributed network architectures, the control and data planes are unified. Satellite nodes must not only forward data packets, but also implement network control functions such as traffic state monitoring, link state maintenance, and route calculation, thus consuming valuable on-board payload and inter-satellite link resources. To meet rising traffic demands and network heterogeneity, Software Defined Network (SDN) can be used to simplify the management of communication networks for future satellite Internet architectures. The Software Defined Satellite Network (SDSN) architecture is a promising solution for monitoring and managing the network more flexibly and facilitating network expansion [5–12].

Currently, researches on SDN-based satellite network routing are focused on the network architecture. However, hierarchical-based SDNs need to consider the reliability of routing policies. On the one hand, the timeliness of routing tables, where the higher-level satellites need to accurately capture the network topology of the lower-level satellites promptly. On the other hand, the robustness of routing policies, where the inter-layer links need to be stable to ensure the effective update of the routing policies of the higher-level satellites. In addition, the SDSN routing algorithms proposed by researchers mainly focus on the guarantee of different QoS. For example, the Software-Defined Routing Algorithm (SDRA) obtains the optimal routing path through a centralized routing policy with only a single QoS goal as the optimization point, while most of the literature does not study the differentiated services for different service requirements deeply enough.

In this paper, we propose a Link-Attributes-based On-Demand Routing (LAODR) scheme in SDSN to enhance the adaptiveness and reliability during data transmission. Specifically, we refer to the typical two-layer architecture in the design of the SDSN framework, consisting of a GEO satellite and a ground computing center acting as the controller. In the LAODR, we take service adaption as the main goal to achieve on-demand routing. Meanwhile, by quantifying the dynamic attributes of links, the control plane can sense the dynamic changes of the network topology in time to ensure the reliability of the routing strategy and achieve dynamic topology adaption. To evaluate the performance of the LAODR algorithm, we developed a satellite network simulation platform based on STK and OMNeT++. Simulation results demonstrate that the proposed algorithm in this paper outperforms the basic algorithms in terms of latency, packet loss ratio, and throughput.

The contribution of this paper is the proposal of the LAODR algorithm under the SDSN architecture, which quantifies the reliability of Inter-Satellite Links, provides a fine-grained state description of the dynamic topology, and efficiently meets diverse service demands while outperforming other routing algorithms in terms of QoS metrics.

The rest of this paper is organized as follows. The framework of the Software-Defined Satellite Network is constructed in Section 2. In Section 3, a link-attributes-based multi-service on-demand routing algorithm is proposed. In Section 4, we give the simulation results and performance analysis. In Section 5, we conclude this paper.

2 SDN-Enabled LEO/GEO Satellite Network Model

Software Defined Network (SDN) will play an important role in the future development of satellite Internet by decoupling the control plane and data plane and simplifying the management of the network. We use a typical multilayer SDSN centralized control framework in this paper, which contains GEO control plane, ground control plane and LEO data plane [13]. The control plane consists of GEO satellites and Ground Computing Center (GCC), where GEO satellites can take advantage of their natural coverage characteristics to collect global traffic information and formulate routing policies, and GCC can take advantage of computing power resources to process the acquired information and mine the routing laws. The data plane is composed of LEO satellites, which only need to provide data transmission services based on the routing table issued by GEO satellites. The architecture is shown in Fig. 1.

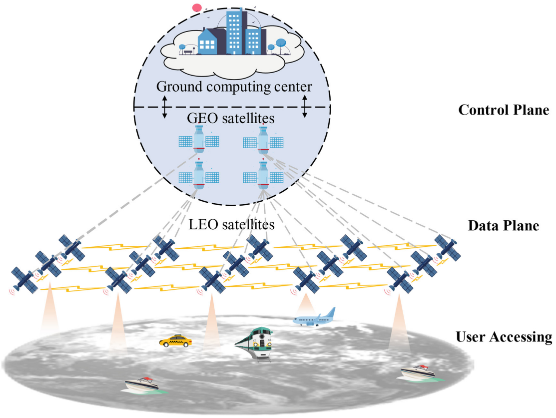

Fig. 1. Software-Defined Satellite Network Architecture.

Control Plane: GEO satellites and GCC. Their main functions are traffic scheduling and access user's path assignment. GEO satellites are responsible for collecting the link traffic state of LEO satellites, such as time slot, satellite location, link load, remaining capacity, etc., to make multi-service routing decisions based on link attributes, and further send network topology information and routing decision results to GCC continuously. The GCC trains the routing model based on the data sent by GEO, predicts the future routing paths from the past traffic and routing laws, and uploads the routing results to GEO satellites with a certain frequency. Then, the GEO satellites integrate its own and the received GCC routing scheme to get a unique routing result that adapts to the state of the satellite network, and sends it forward to the data plane. Based on this architecture, the GEO satellites are used as the primary controller and the GCC as the secondary controller to ensure the timeliness and accuracy of routing decisions, and alleviate the limitation of on-board computing resources.

Data Plane: LEO satellites. Their main functions are request upload, network traffic status upload and data transmission. The LEO satellites periodically upload the network link status information and transmission request to the GEO satellites, and transmits the packets according to the routing table returned from the GEO satellites. Since the LEO satellites transfer the decision of routing to the GEO satellites, it greatly reduces the demand for onboard computing resources.

On the one hand, the GCC utilizes the periodic predictability of satellite topology change and collects the routing decision results of GEO satellites in the early stage for regular analysis; in the later stage, the regular routing forwarding strategy can be uploaded to GEO satellites to assist GEO satellites' routing decision. On the other hand, the data forwarding of LEO is still dominated by GEO's decision, which ensures the timeliness of the routing strategy and reduces the impact of long-distance ISL on routing reliability. In addition, since the routing decisions are made at the GEO satellites, the data forwarding of the LEO satellites, the training and updating of the GCC model, and the routing strategy formulation by the GEO satellites can occur in parallel, minimizing the impact of the model update on the routing performance.

3 Design of LAODR

In this section, a satellite network description is given to analyze the properties of ISN first. Then, link utilities are quantified to portray the reliability of links, which are used as a decision metric for target optimization in the routing model. Finally, a Link-Attributes-based multi-service On-Demand Routing (LAODR) algorithm is designed to achieve adaptive routing for dynamic topologies and multiple services.

3.1 Description of the LEO Satellite Network

Satellites often establish communication links with surroundings via microwave/laser Inter-Satellite Links (ISLs). Generally, each node is interconnected with four surrounding satellites to establish ISLs. Among them, the satellite establishes two ISLs in the same plane, called Intra-plane ISL, and the two other interplanetary links with satellites in different planes, called Inter-plane ISL. If a satellite enters the polar region, its Inter-plane ISL will be disconnected due to antenna tracking limitations, while the Intra-plane ISL mostly remains connected. The Inter-plane ISL is also temporarily broken when the angle of view or distance between two satellites changes too rapidly, which happens between two counter-rotating orbits when two planes are close or crossed.

We use Iridium constellation as the study object for LEO satellite routing, and a network topology schematic is established as shown in Fig. 2. The Iridium constellation consists of 6 orbits, each containing 11 LEO satellites. It should be noted that the polar region boundary is assumed to be 70° in this paper, and once the satellites enter the polar region, the Inter-plane ISLs are broken, while the Intra-plane ISLs continue to be maintained. Therefore, the Inter-plane ISLs in the red region do not exist. Also, the Inter-plane ISLs between Plane 1 and Plane 6 do not exist due to the reverse seam.

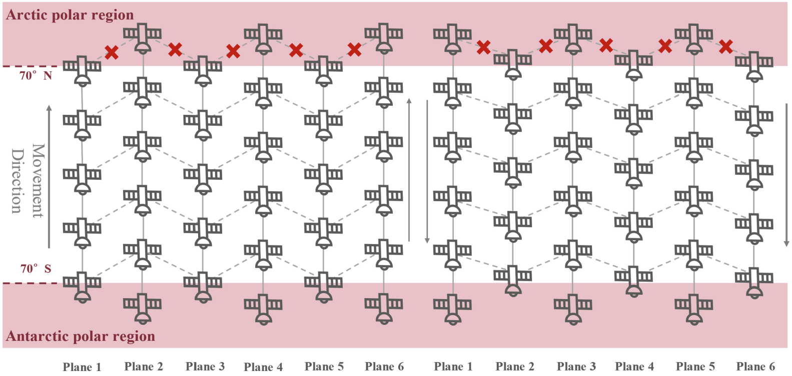

Fig. 2. Satellite Network Topology.

3.2 Quantification of Dynamic Link Attributes

Due to the dynamic nature of satellite networks, the ISL's state changes with the motion of satellites, and ISL's attributes such as Signal-to-Noise Ratio (SNR) [14], link duration [15] and buffer queue [16] affect the reliability of routing paths. Existing studies only describe the link states as simply on and off, which can easily cause unreliability of routing paths due to untimely and incomplete updating of link state information. These dynamic attributes can be quantified as the utility of ISLs to improve the adaptability of satellite routing to dynamic topologies [17]. We define these dynamic link attributes (SNR, link duration and buffer queue) as $\{U_S, U_L, U_B\}$, respectively.

First, to ensure the correct reception of data, the SNR of the receiving satellite should be greater than the reception threshold, as in (1). Second, to ensure the stability of transmission, ISLs with longer link duration should be selected as much as possible, as in (2). Third, satellites must have sufficient buffer queues to store and process packets, as in (3). Therefore, the dynamic characteristics of ISLs can be characterized to further quantify the impact of link attributes on communication quality.

$$U_S = P_r\left(SNR_{ij} > \gamma_0\right) = \int_{\gamma_0}^{\infty} SNR_{ij}dx = \int_{\gamma_0}^{\infty} \frac{\left|h_{ij}(t)\right|^2 L_{ij}^{-\gamma}(t)G}{N_0}dx \tag{1}$$

where SNR_{ij} is the SNR of ISL between satellite i and j, the SNR_{ij} threshold is γ_0, h_{ij} is the channel characteristic, L_{ij} is the ISL's length, G represents the state of satellite, which is constant if it works normally, otherwise 0, and N_0 is the link noise power.

After a satellite enters the polar region, the Inter-plane ISL will be broken and only the Intra-plane ISL will continue to be maintained. Therefore, the duration of the link depends greatly on the latitude position of the satellite in the absence of sudden satellite failure. Let the starting moment of the link connection be t_{ij}^{on}, the disconnection moment be t_{ij}^{off}, and the current moment be t, with $t_{ij}^{on} \leqslant t \leqslant t_{ij}^{off}$. From the maximum link duration $l_{ij}^{\max} = t_{ij}^{off} - t_{ij}^{on}$ and the link duration $l_{ij}^{\Delta} = t_{ij}^{off} - t$, we can obtain:

$$U_L = \begin{cases} \frac{l_{ij}^{\Delta}}{l_{ij}^{\max}} & i, j \text{ in different orbits} \\ 1 & i, j \text{ in the same orbit} \end{cases} \tag{2}$$

Based on the queuing theory *M/M/1/N/*∞ model, where N is the capacity of the satellite buffer queue, assume that the arrival of packets obeys Poisson distribution, and set the packet flow rate λ, the satellite processing rate μ, the existing queue length n_{ed}, the current service packet size m, service capacity ρ. From the sojourn time of the service W_S, the minimum sojourn time of the service $W_{\min}$ and the packet loss ratio of the service P_B, we can calculate:

$$U_B = \frac{W_{\min}}{W_S}(1 - P_B) = \left(\frac{m}{\mu}\right) / \left(\frac{n_{\text{ed}} + m}{\mu}\right) \cdot \left(1 - \frac{(1-\rho)\rho^N}{1-\rho^{N+1}}\right) \tag{3}$$

The above three link dynamic attribute utilities are combined into a link utility U_{ij} to characterize the link reliability. The link utility U_{ij} can be expressed as follows:

$$U_{ij} = U_{S_{ij}}^{w_s^{ij}} \cdot U_{L_{ij}}^{w_l^{ij}} \cdot U_{B_{ij}}^{w_b^{ij}} \tag{4}$$

where w_s, w_l, w_b are the contribution weights of each attribute utility to the link utility calculated by the entropy value method, with $w_s^{ij} + w_l^{ij} + w_b^{ij} = 1$.

The link utility calculated in this part can well evaluate the dynamic properties of ISLs. It can predict the trend before link disconnection, reconstruction or node congestion occurs, which evaluates the reliability of the link to reduce the retransmission problem caused by packet loss and realize the self-adaptation to dynamic topology.

3.3 Link-Attributes-Based Multi-service On-Demand Routing

With the increasing number of satellites, the Satellite Internet will carry a richer range of services, which have different needs for Quality of Service (QoS). So how to design a differentiated routing scheme for services has become a key issue.

Table 1. QoS requirements for different services.

Category	Bandwidth	Latency	Reliability	Applications
Voice Stream	Low	High	Medium	IP Phone
Video Stream	High	Low	Medium	Video on Demand
Data stream	Medium	Medium	High	FTP, File Transfer

The service or QoS classifications defined by various standardization organizations are not the same, and it is difficult to achieve interoperability of multiple QoS routes without uniform classifications. We mapped the typical classifications and completed a brief service classification based on QoS requirements, as shown in Table 1. For example, voice and calls belong to delay-sensitive services; video belongs to bandwidth-sensitive services; and file transfer belongs to reliability-sensitive services.

Three-dimensional vectors (B, D, R) are used to indicate the comprehensive sensitivity of each type of service, where they represent path bandwidth, delivery delay, and path reliability, respectively. If the available bandwidth of each link is denoted as B_{ij}, the bandwidth occupied by the task B cannot exceed the minimum value of B_{ij}, $B \leqslant \min\left(B_{ij}, B_{jk}, \cdots, B_{mn}\right)$. If the link delay between two adjacent satellites is d_{ij}, the path delivery delay $D = \sum d_{ij}$. The link utility U_{ij} is obtained from the previous section, and the reliability of the path $R = U_{ij} \times U_{jk} \times \cdots \times U_{mn}$.

Algorithm 1: LAODR

```
Input: satellite latitude and longitude, network information (traffic, available bandwidth,
queue length, packet loss rate, service requirements).
Output: next-hop nodes of different business types ($nxt\_A,\ nxt\_B,\ nxt\_C$).
Initialize satellite network environment and network load;
for $s_i \in S$ do
    for $s_j \in S$ do
        Calculate the link attributes $U_{S_{ij}}, U_{L_{ij}}, U_{B_{ij}}$ of the link $e_{ij}$;
        Get the link utility $U_{ij} = {U_{S_{ij}}}^{w_s} \cdot {U_{L_{ij}}}^{w_l} \cdot {U_{B_{ij}}}^{w_b}$;
        Quantifying link latency $d_{ij}$, link available bandwidth $B_{ij}$, and link reliability $U_{ij}$;
    end for
end for
for $s_i \in S$ do
    for $s_j \in S$ do
        Compute the optimal set of paths $Path\{s_i \rightarrow s_j\}$;
        for $p_k \in Path\{s_i \rightarrow s_j\}$ do
            Calculate the path delay $D$, path bandwidth $B$, and path reliability $R$;
            Define optimization goals $\{\min\ D,\ \min\ B_I - B,\ \min\ R_I - R\}$;
            Choose the $p_k$ that minimizes $Z_k = W_B \cdot (B_I - B) + W_D \cdot D + W_R \cdot (R_I - R)$;
        end for
        Get the next hop node $nxt = p_k[1]$ of $s_i \rightarrow s_j$;
    end for
end for
Store the $nxt\_A,\ nxt\_B,\ nxt\_C$ of all satellite node pairs;
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To achieve on-demand routing of services and full utilization of resources, the Multi-Objective Planning (MOP) model can be established, where the bandwidth, delay and reliability requirements of a service are b_n, d_n, r_n, as well as the ideal bandwidth, delay and reliability of the path are B_I, D_I, R_I We use the eigenvector method to solve the MOP model by assigning different weights $\boldsymbol{w} = [W_B, W_D, W_R]$ to different types of service QoS metrics. And transforming the MOP problem into a single-objective planning problem:

$$\begin{aligned} &\min Z = W_B \cdot Z_B + W_D \cdot Z_D + W_R \cdot Z_R \\ &\text{s.t.} \begin{cases} Z_B = B_I - B, \quad Z_D = D, \quad Z_R = R_I - R \\ \quad\; B \geqslant b_n, \quad D \leqslant d_n, \quad R \geqslant r_n \end{cases} \end{aligned} \tag{5}$$

Finally, to achieve a trade-off between reducing the computational complexity and ensuring the adaptation to the satellite topology, the paths are selected optimally, i.e., K shortest paths. The Dijkstra algorithm is used to calculate the set of the first optional paths between the source and destination nodes. The optimal paths satisfying (5) are solved iteratively to obtain on-demand routing policies for different service types. The designed LAODR algorithm implements adaptive routing for dynamic topologies and multiple services, and the overall algorithm pseudo-code is as Algorithm 1.

4 Evaluation

4.1 Experimental Setup

We first use the Standard Object Database (SOD) in the STK11.2 simulator to construct a satellite topology that meets the practical application and obtain the real-time latitude and longitude data of each satellite. In the control plane, four GEO satellites are deployed at equal intervals for global control and one GCC is located at Beijing for routing algorithm training and updating. In the data plane, the Iridium system, which is widely used in simulations, is deployed. Then, based on OMNeT + +5.6.2, we establish the algorithm simulation and verification platform, import the scenario of STK simulation by Python, build the control node and forwarding node, and control the disconnection and reconstruction of the ISL. Each packet generation rate is set to obey uniform distribution from 200 Kbps to 2000 Kbps and different tasks are labeled with sensitivity labels, where the percentages of delay-sensitive, bandwidth-sensitive and reliability-sensitive services are 0.2: 0.3: 0.5, respectively. The weight matrix of different services $\boldsymbol{w} = [W_B, W_D, W_R]$ in (5) is calculated by the eigenvector method. The main simulation parameters in this paper are shown in Table 2.

The designed algorithm LAODR results are compared with existing algorithms (e.g., classical Dijkstra's algorithm, IADR algorithm considering only link utility [17]) to verify and analyze five performance metrics. To ensure the reliability of the results, the average value of five experiments is taken as the simulation result.

Dijkstra: packets are calculated based on dijkstra algorithm to get the shortest path between node pairs, which has the minimum number of hops, but the performance is significantly degraded due to congestion when the traffic load is high.

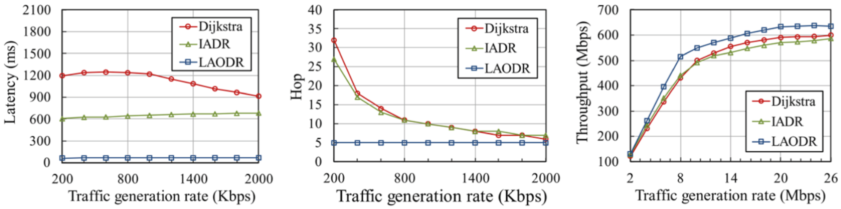
IADR (ISL Attributes-based Dynamic Routing): To improve the adaptability and reliability of LEO satellite network routing, IADR quantifies the link utility based on ISL attributes such as SNR, link duration and buffer queue. A routing path optimization model is constructed based on the multi-attribute decision scheme.

Table 2. Simulation parameters setting.

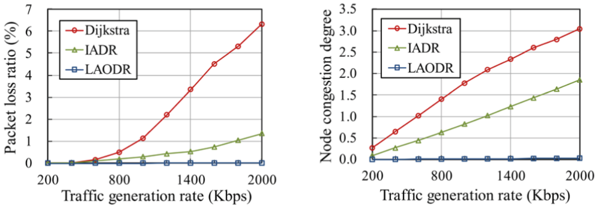
Parameter	Value	Parameter	Value
Polar region boundary	70°	Laser beam divergence half-angle	5e–3 rad
ISL Bandwidth	20 Mbps	Tracking error angle θ	1 mrad
ISL propagation delay	15 ms	SNR threshold γ_0	20 dB
Packet length	2 Kbytes	Transmitting power G	4 dBm
Buffer queue size	800 packets	Noise power N_0	1e–14 dBm
Switch processing latency	0.1 ms	Simulation time	100 s
Traffic generation rate	200–2000 Kbps	Routing calculation time step	1 s

4.2 Performance Evaluation Under Different Traffic Loads

Figure 3 (a) gives the comparison curves of the time delay for different traffic loads. Both IADR and LAODR algorithms increase slowly as the traffic increases, while the latency of Dijkstra's algorithm increases and then decreases. Dijkstra is prone to network congestion when the traffic is high, resulting in packet drops. The IADR and LAODR take the "buffer queue" attribute of the link into account, which can better balance the traffic across the network. LAODR algorithm has the lowest latency and compare to Dijkstra and IADR with 94.07% and 89.74% latency reduction. Figure 3 (b) shows the average hop count for different traffic loads. Dijkstra has a large instability on hop under different traffic sizes, and when the traffic volume increases, there is a sharp decay in the hop count, which is due to the large packet loss. The proposed LAODR algorithm has the most stable hop count with 59.02% and 57.27% reduction compared to Dijkstra and IADR. Figure 3 (c) compares the throughputs under different traffic loads. Since the three algorithms do not deliberately pursue network load balancing under low traffic, all have similar network throughput in the early stage. LAODR makes full use of LEO satellite resources to improve the data transmission efficiency of the satellite network, so the data transmission per second is improved by 8.25% and 10.13% compared with Dijkstra and IADR. Figure 3 (d) compares the packet loss performance. All three algorithms have a low packet loss ratio when the traffic is small. Since the Dijkstra scheme pursues the smallest transmission delay, all tasks are assigned to the shortest distribution path, which easily causes link overload and increases burst link congestion and causes packet loss. Thus, with the increase of traffic, the packet loss performance of Dijkstra decreases significantly. The IADR algorithm can select links with long link durations, and therefore, the packet loss ratio grows slowly and with smaller values. It is worth noting that the proposed LAODR algorithm not only considers the link stability, but also optimizes the traffic distribution of the network in multi-service on-demand routing. As a result, a low packet loss ratio can still be guaranteed when the traffic is high. The satellite congestion is evaluated in Fig. 3 (e). As the traffic increases, the node congestion degrees show an increasing trend. It is observed that Dijkstra has the largest congestion, IADR is the second and the proposed LAODR scheme has the smallest. LAODR takes each node load into account, thus alleviating the traffic imbalance problem. Compared with other algorithms, LAODR can utilize more nodes for pathfinding and thus has the best congestion performance. LAODR reduces node congestion by 99.26% and 98.59% compared to Dijkstra and IADR.



(a) Latency. (b) Hop. (c) Throughput.



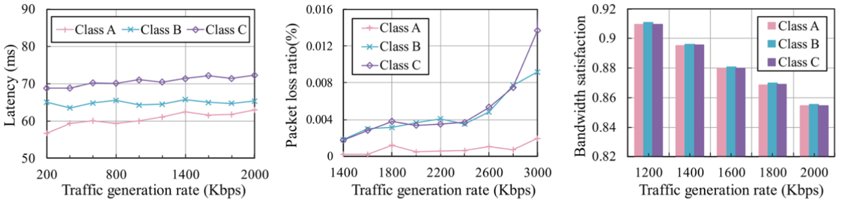
(d) Packet loss ratio. (e) Node congestion degree.

Fig. 3. Performance comparison of each algorithm under different traffic loads.

4.3 Performance Evaluation of Different Services

Meanwhile, the performance of the LAODR algorithm for different services is compared. The following Class A represents delay-sensitive services, Class B represents bandwidth-sensitive services, and Class C represents reliability-sensitive services.

Figure 4 (a) shows the latency of different services in LAODR. It can be found that Class A has higher delay requirements and therefore have lower routing delay compared to other types of services. Class C services have lower delay requirements and therefore have a higher delay, and they choose paths with larger hop counts to provide more choice for Class A. Figure 4 (b) shows the packet loss performance of different services. When the traffic is small, Class A has the smallest number of packets and higher priority making the packet loss performance excellent, while Class B does not require a high packet loss ratio, so the packet loss performance is poor. As the traffic load increases, the overall packet loss performance of Class C is gradually inferior to that of other services because the traffic volume of class C services is larger. Overall, the packet loss ratio of Class C is less than 0.015%, which has good routing reliability. Figure 4 (c) shows the bandwidth satisfaction for different services. This performance metric provides a good representation of the bandwidth enhancement space for different service routing paths. Class B is bandwidth-sensitive service, which requires more bandwidth and has better bandwidth satisfaction than other types of services.



(a) Latency. (b) Packet loss ratio. (c) Bandwidth satisfaction.

Fig. 4. Comparison of routing performance of different services of LAODR.

In summary, the paths assigned by the LAODR can better meet the QoS requirements of users and have good sensing capability for the link on/off and node failure. In contrast, the Dijkstra and IADR methods rarely consider user requirements and show poor identification ability for delay-sensitive and reliability-sensitive services.

5 Conclusion

This paper focuses on the problem of designing adaptive routing algorithms under the Software-Defined Satellite Networks (SDSN) architecture. Considering the dynamic characteristics of satellite network topology and the differentiated service demands of users, the LAODR scheme provides a fine-grained portrayal of link reliability attributes, based on which a multi-objective on-demand routing model is established to realize adaptive routing for dynamic topology and multiple services. The SDN framework is fused with the routing model to achieve efficient ISN traffic control and load balancing. Simulation results demonstrate that the proposed LAODR routing algorithm has superior traffic control performance and flexibility in routing, enabling efficient utilization of network resources to fulfill the varying service requirements of users. In the future, further investigation into the design of the routing prediction algorithm of the auxiliary controller GCC in the SDSN framework can be conducted to explore how to extract relevant regular big data and generate periodic routing policies.

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