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A multipath routing algorithm for satellite networks based on service demand and traffic awareness

Key words: Software-defined network (SDN); Quick user datagram protocol Internet connection (QUIC); Reinforcement learning; Sketch; Multi-service demand; Satellite network

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Motivation

1. In low Earth orbit (LEO) satellite multi-service demand routing, different service demands are mixed together.
2. Fine-grained operations have not been proposed yet with network traffic in LEO satellite.
3. How to design a dynamic topology to verify the multipath routing of the LEO satellite network based on service demand and traffic awareness?

Method

Save multi-service flag in QUIC packets

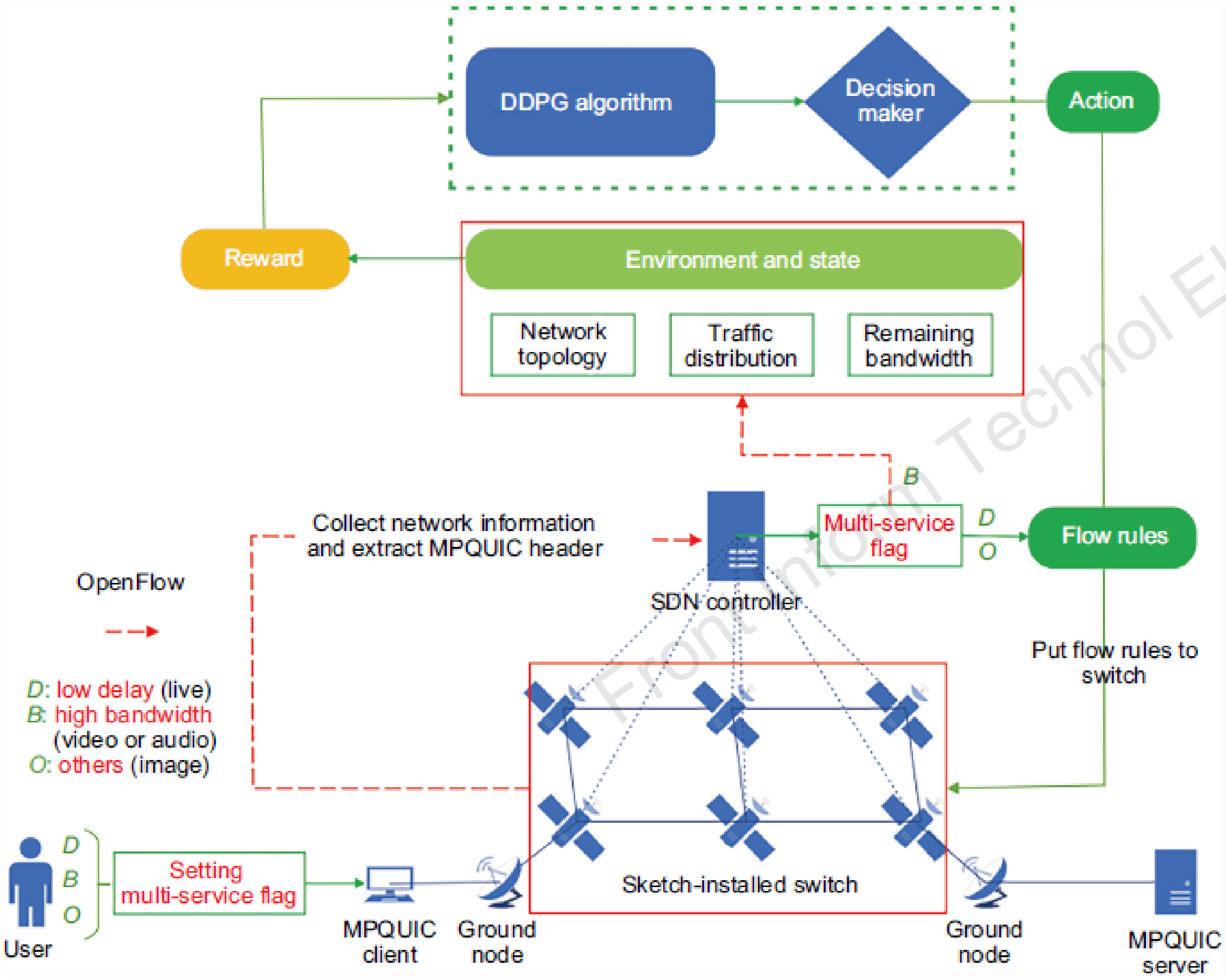


Fig. 3 System architecture (a client sends a request to the remote server, and the server will push data to a client with multiple paths by the request)

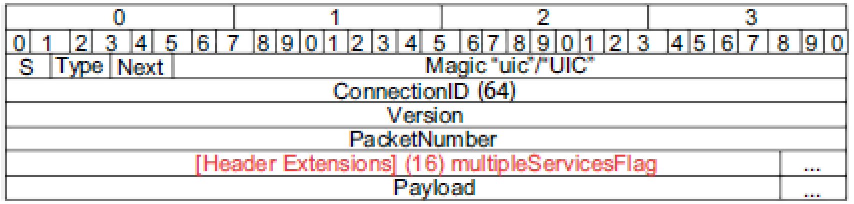


Fig. 4 Location of the multi-service flag in QUIC packets

Method

Guarantee a highly accurate data flow rate measurement method: sketch

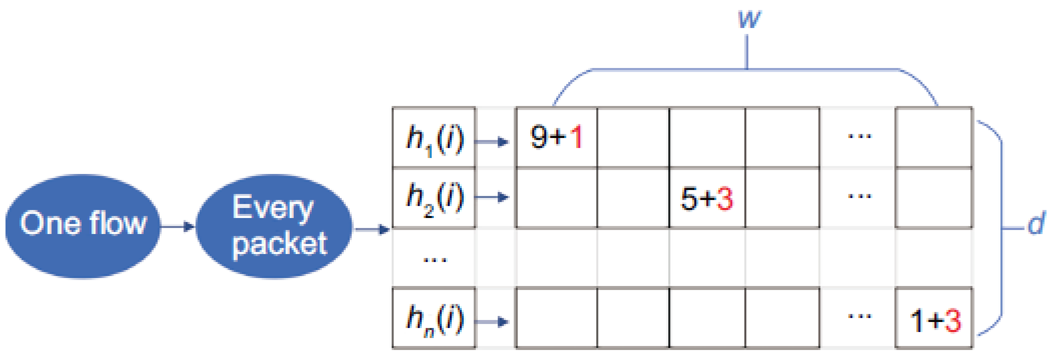


Fig. 5 Sketch data flow measurement principle

$$\text{counter}(\text{element}, \text{hash}(\text{element})_{\text{row}}) += \text{value}_{\text{time}}. \quad (4)$$

$$\text{query}(\text{element}) = \min(\text{counter}(k, \text{hash}(\text{element})_{\text{row}})), \ k \in [1, x]. \quad (5)$$

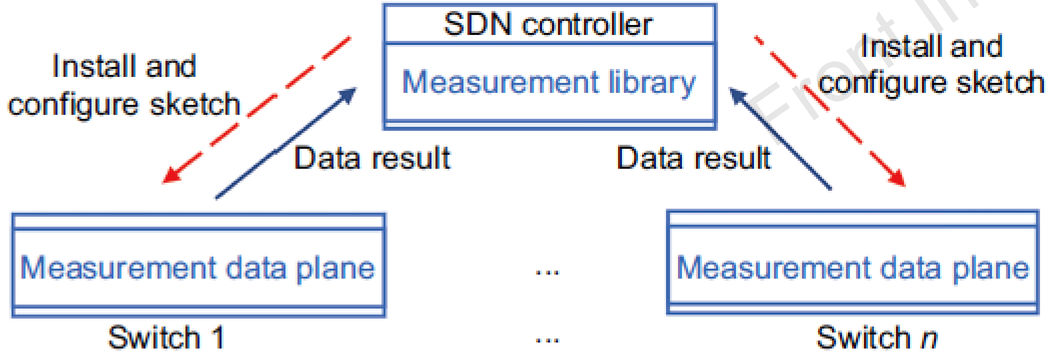
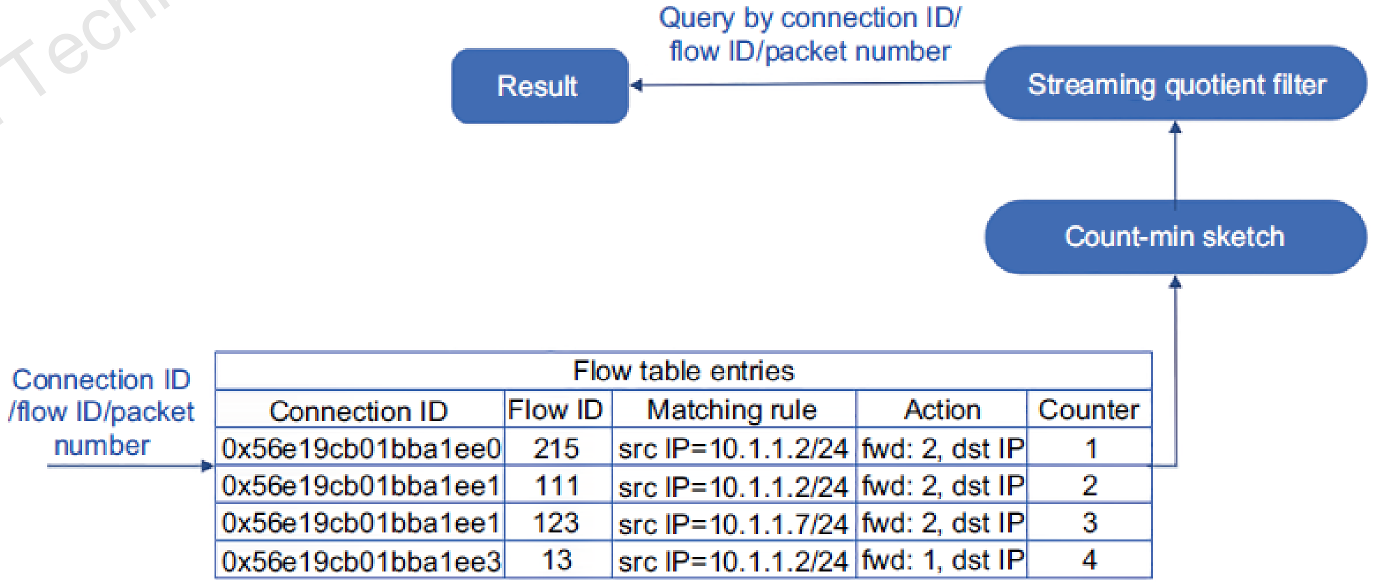


Fig. 6 Software-defined network (SDN) application sketch flow measurement framework



Connection ID	Flow ID	Matching rule	Action	Counter
0x56e19cb01bba1ee0	215	src IP=10.1.1.2/24	fwd: 2, dst IP	1
0x56e19cb01bba1ee1	111	src IP=10.1.1.2/24	fwd: 2, dst IP	2
0x56e19cb01bba1ee1	123	src IP=10.1.1.7/24	fwd: 2, dst IP	3
0x56e19cb01bba1ee3	13	src IP=10.1.1.2/24	fwd: 1, dst IP	4

Fig. 7 Principle of calculating the MPQUIC data flow size in a sketch

Method

Online learning of routing decision with deep deterministic policy gradient (DDPG)

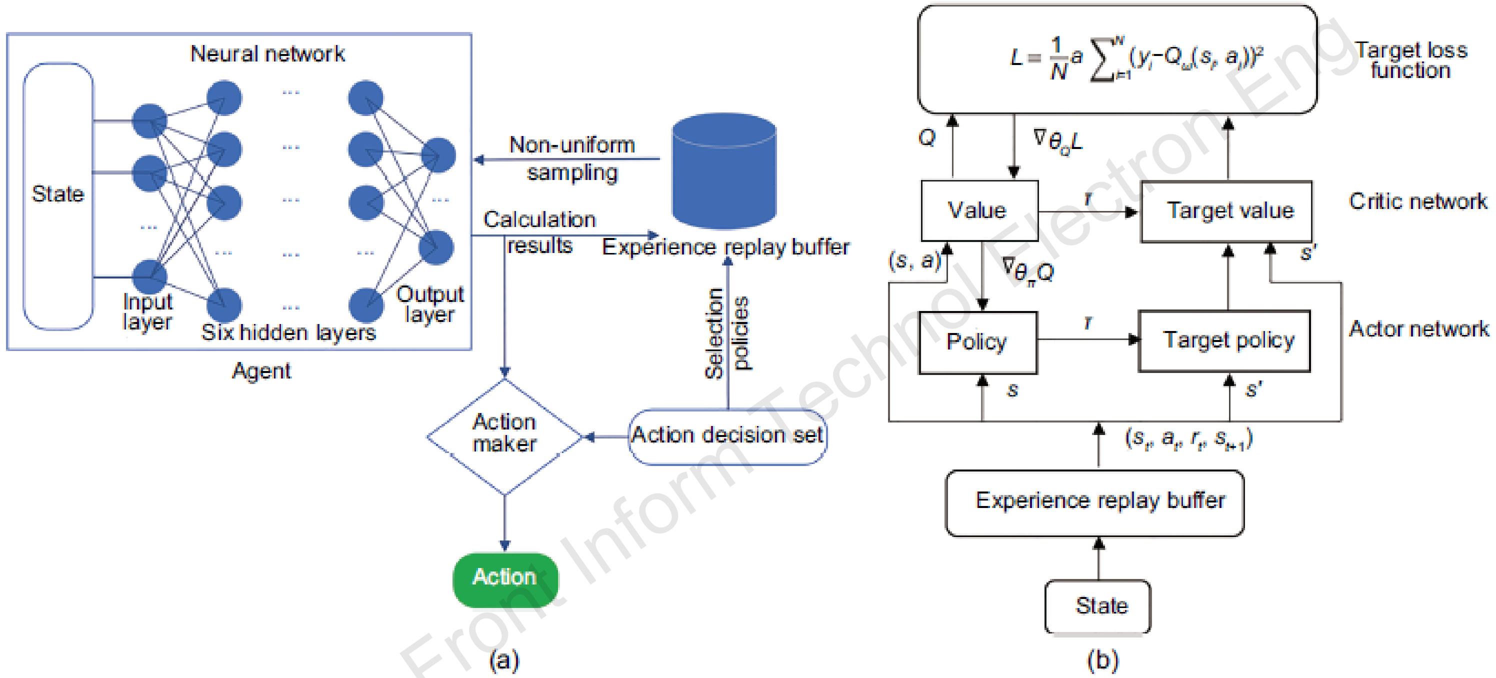


Fig. 9 Deep deterministic policy gradient procedure for routing decisions: (a) online learning of routing decisions; (b) actor network and critic network

State:

$$s = (\mathrm{connectonID}, \mathrm{flowID}, \mathrm{packetNumber}, \mathrm{sourceIP}, \mathrm{destinationIP}, \mathrm{multipleServicesFlag}, \mathrm{remainingBandwidth}). \quad (6)$$

Method

The whole simulation process of the periodic on-off of satellites

The distance matrix ***D′*** is converted into a visible matrix ***D***.

$$
D' = \begin{bmatrix} 1 & D_{(1,2)} & D_{(1,3)} & \cdots & D_{(1,k)} \\ D_{(2,1)} & 1 & D_{(2,3)} & \cdots & D_{(2,k)} \\ D_{(3,1)} & D_{(3,2)} & 1 & \cdots & D_{(3,k)} \\ D_{(4,1)} & D_{(4,2)} & D_{(4,3)} & \cdots & \cdots \\ D_{(5,1)} & D_{(5,2)} & D_{(5,3)} & \cdots & 1 \end{bmatrix}. \tag{8}
$$

$$
D = \begin{bmatrix} 0 & D_{(1,2)} & D_{(1,3)} & \cdots & D_{(1,k)} \\ D_{(2,1)} & 0 & D_{(2,3)} & \cdots & D_{(2,k)} \\ D_{(3,1)} & D_{(3,2)} & 0 & \cdots & D_{(3,k)} \\ D_{(4,1)} & D_{(4,2)} & D_{(4,3)} & \cdots & \cdots \\ D_{(5,1)} & D_{(5,2)} & D_{(5,3)} & \cdots & 0 \end{bmatrix}. \tag{9}
$$

A dynamic network is created

Algorithm 2 Iridium constellation dynamic network

Input: matrix $D\left(D^1, D^2, \cdots, D^N\right), N = 66, \Delta t = 60$ s
Output: NULL

for each $D^n! = \text{null}$ **do**
  if $D^n = D^{\Delta t+n}$ **then**
    do nothing
  else if $D^n_{(j,k)} \, != D^{\Delta t+n}_{(j,k)}$ and $D^{\Delta t+n}_{(j,k)} = 1$ **then**
    put $D^n_{(j,k)}$ and $D^{\Delta t+n}_{(j,k)}$ up
  else if $D^n_{(j,k)} \, != D^{\Delta t+n}_{(j,k)}$ and $D^{\Delta t+n}_{(j,k)} = 0$ **then**
    put $D^n_{(j,k)}$ and $D^{\Delta t+n}_{(j,k)}$ down
  end if
end for

Conclusions

1. A sketch-based network traffic analysis method based on a software-defined network (SDN) has been proposed to realize fine-grained operations.

2. We propose an artificial intelligence multi-service driven and traffic-aware routing scheme to convert different service demands and network states into reinforcement learning reward functions to achieve real-time dynamic routing.

3. To verify the multipath routing of the LEO satellite network based on service demand and traffic awareness, the iridium constellation is designed with a dynamic topology.

Xiaoqiang DI received his BS degree in computer science and technology from Changchun University of Science and Technology in 2002, and his MS and PhD degrees in communication and information systems from Changchun University of Science and Technology in 2007 and 2014, respectively. He was a visiting scholar at Norwegian University of Science and Technology, Norway, from Aug. 2012 to Aug. 2013. He is currently a professor in Changchun University of Science and Technology. His major research interests include network information security and integrated network.