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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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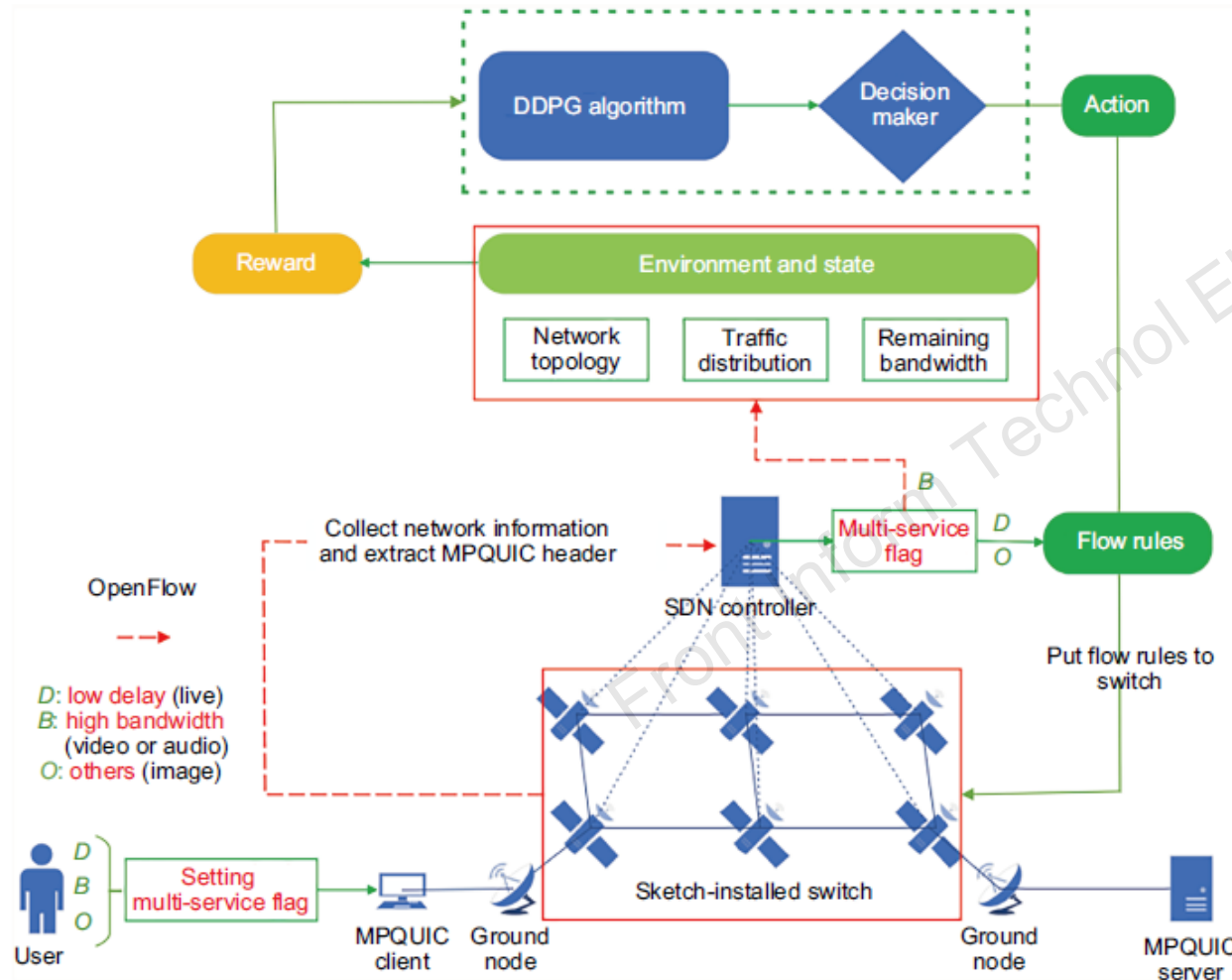
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Motivation

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



0								1								2								3									
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0			
S								Type								Next								Magic "uic"/"UIC"									
ConnectionID (64)																																	
Version																																	
PacketNumber																																	
[Header Extensions] (16)																								multipleServicesFlag								...	
Payload																																...	

Fig. 4 Location of the 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)

Method

Guarantee a highly accurate data flow rate measurement method: **sketch**

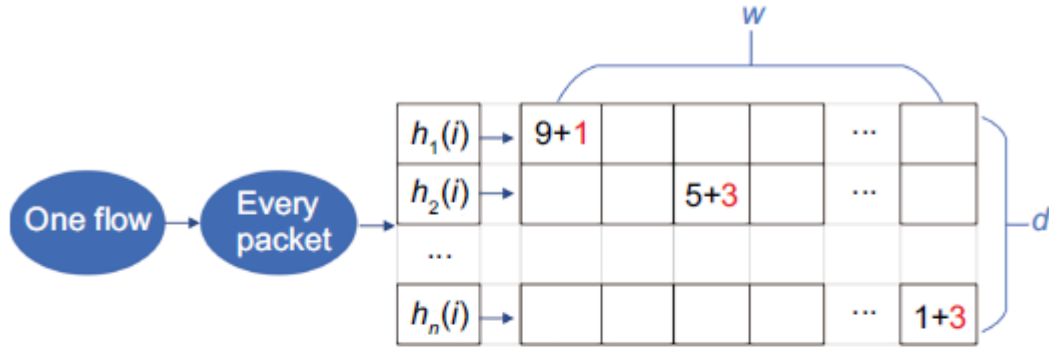


Fig. 5 Sketch data flow measurement principle

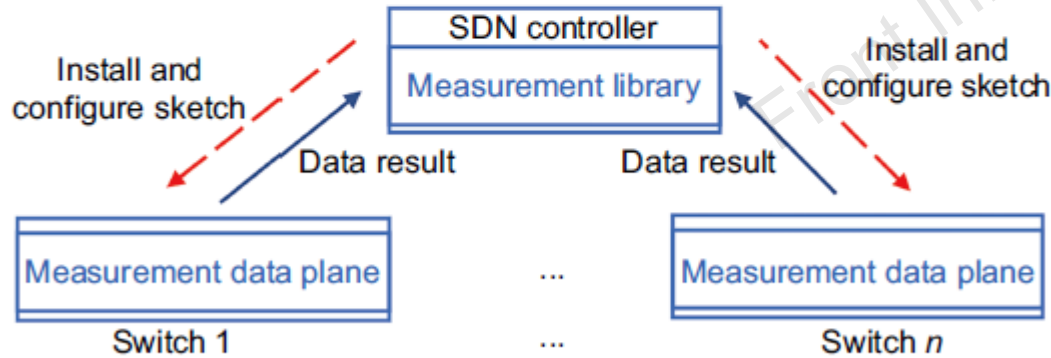


Fig. 6 Software-defined network (SDN) application sketch flow measurement framework

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

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

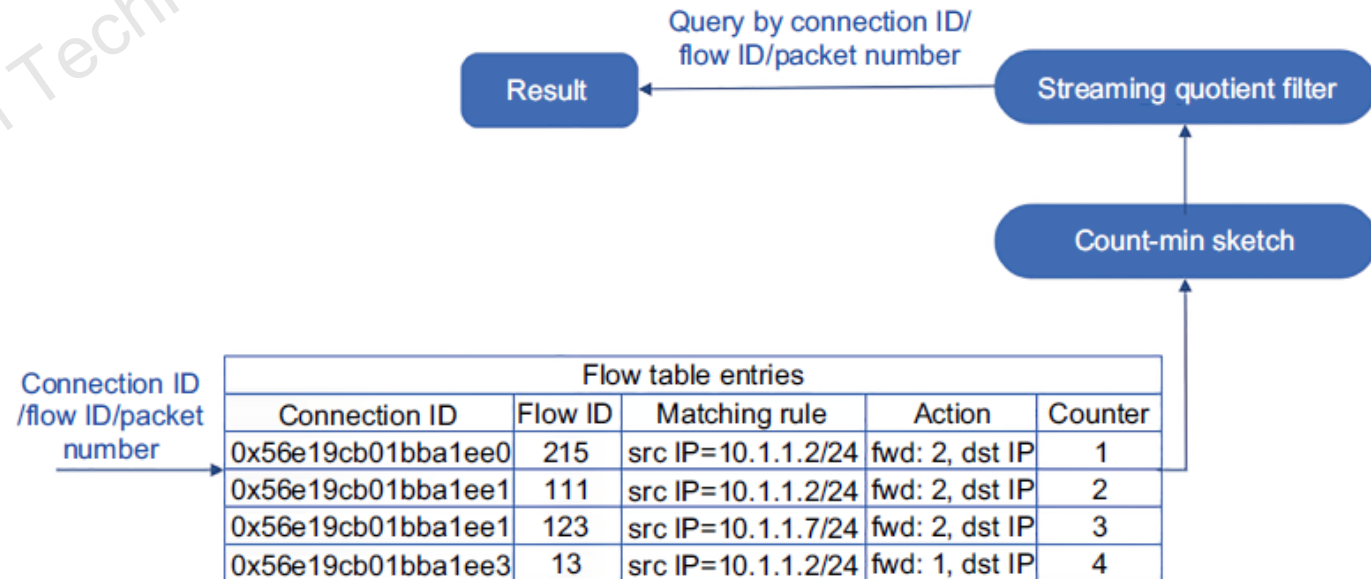


Fig. 7 Principle of calculating the MPQUIC data flow size in a sketch

Method

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

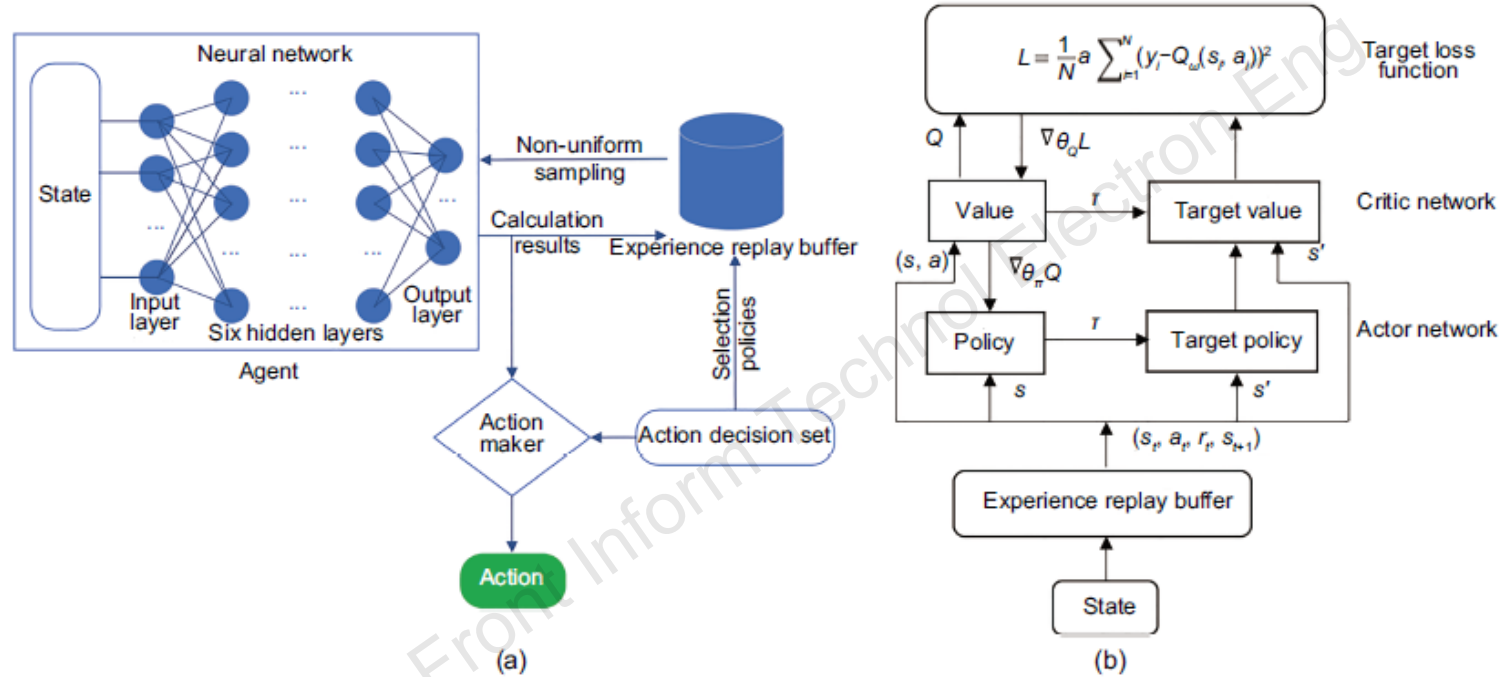


Fig. 9 Deep deterministic policy gradient procedure for routing decisions: (a) online learning of routing decisions; (b) actor network and critic network

State:

$s = (\text{connectionID}, \text{flowID}, \text{packetNumber}, \text{sourceIP},$
 $\text{destinationIP}, \text{multipleServicesFlag},$
 $\text{remainingBandwidth}).$

Method

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

The distance matrix D' is converted into a visible matrix D .

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

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

A dynamic network is created

Algorithm 2 Iridium constellation dynamic network

Input: matrix D ($D^1, D^2, \dots, D^N$), $N = 66, \Delta t = 60$ s

Output: NULL

```

1: for each  $D^n \neq \text{null}$  do
2:   if  $D^n = D^{\Delta t+n}$  then
3:     do nothing
4:   else if  $D_{(j,k)}^n \neq D_{(j,k)}^{\Delta t+n}$  and  $D_{(j,k)}^{\Delta t+n} = 1$  then
5:     put  $D_{(j,k)}^n$  and  $D_{(j,k)}^{\Delta t+n}$  up
6:   else if  $D_{(j,k)}^n \neq D_{(j,k)}^{\Delta t+n}$  and  $D_{(j,k)}^{\Delta t+n} = 0$  then
7:     put  $D_{(j,k)}^n$  and  $D_{(j,k)}^{\Delta t+n}$  down
8:   end if
9: 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.