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Load-Balancing Routing with Hybrid Network Considering Bandwidth Ratio

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The amount of traffic using mobile networks based on cellular and/or WiFi communications has increased because of the growth of large-capacity services such as high quality video application (sending and receiving data) due to the spread of smartphones. With the increase in traffic volume, there is a concern about communication failure due to the increased communication load in mobile networks. Therefore, a mechanism is needed to suppress network congestion so that applications can be used even in situations where there is heavy traffic volume. One countermeasure is to improve the routing protocol in the mobile networks. The existing routing protocol is a single route control using the optimum route, so traffic is concentrated on links and nodes, and the risk of congestion increases. As a solution to this problem, in this study, we propose the method of multiple routes controlled by distributed transfer in accordance with the bandwidth ratio for redundant routes other than the optimal route during packet transfer. As a result, the utilization rate of the entire network can be expected to improve and congestion will be suppressed. We have evaluated the proposed method and OSPFv2 (Open Shortest Path First Version2) and showed the proposed method has superior throughput and packet loss rate. Finally, we demonstrate that the proposed method has no bias in the packet arrival rate.

Key words: hybrid network, routing, OpenFlow, bandwidth

1. Introduction

The amount of traffic using mobile Internet has been increasing because of the remarkable growth of large-capacity services such as high quality video applications (sending and receiving data) due to the spread of smartphones. The global mobile data volume is expected to be nearly 1.5 times greater than the current by 2020. With this increase in traffic volume, there is a concern about communication failure due to the increase in the communication load in mobile networks. In fact, domestic ISPs (Internet Service Providers) have reported cases of communication failure due to delay or packet loss. Therefore, a mechanism is needed to suppress network congestion so that applications can be used even when traffic is huge. In particular, traffic and payment related applications should be able to be used smoothly. One measure to solve the above problem is to improve the routing protocol in the mobile networks. Existing routing protocols are based on single route control using the optimal route, which has the disadvantage that traffic concentrates on links and nodes, increasing the risk of congestion.

As a solution to this problem, multi-path control using multiple paths for transmission by using redundant paths leading to destination nodes other than the optimal path is conceivable[1]. As a

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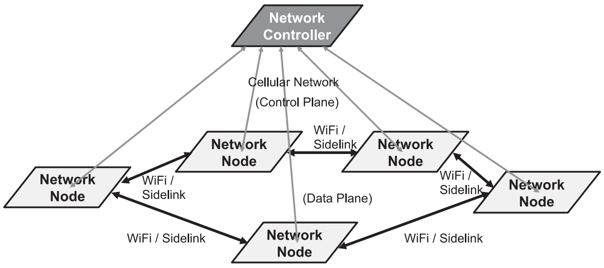

Fig. 1. Hybrid network architecture.

result, the utilization rate of the entire network can be expected to improve, and congestion can be suppressed.

In this study, flexible route control is performed by using two kinds of communications. One is a data plane, which is a direct data communication part between nodes. The other is a control plane, which is a control communication part between the controller and the node that performs transmission control. We assume the data plane is on direct WiFi (or PC5 sidelink) communication and the control plane is on cellular communication. The network architecture based on two kinds of communication paths is called a hybrid network (Fig. 1). This technology realizes flexible routing control using redundant routes.

2. Related Research

2.1 *OSPF optimized multipath*

Villamizar proposesd OSPF (Open Shortest Path First)[2], which is an OSPF-OMP (Optimized Multipath) multi-path control considering real-time traffic[3]. Each router periodically collects the link load status of the entire network and performs route control so as to solve the maximum flow problem. Each router realizes dynamic multipath control by calculating multiple equal-cost paths using OSPF and adjusting the packet transmission probability so that the link load state of each path becomes uniform[4]. However, since the load information packets for each link of each router are mixed on the network, the bandwidth becomes tight. Furthermore, since the packet transmission probability is adjusted so that the load becomes uniform, the route convergence is extremely slow, and the packet throughput is reduced.

2.2 *Proposal of TCP traffic dynamic route distribution network using Openflow*

Yoshimura et al. improved the Dijkstra method and used multiple routes from the optimal route to more than three hops as communication channels. In addition, the routing method uses OpenFlow[5] to re-select the route on the basis of the current load information of each link and achieves dynamic multi-path control[6].

However, to perform dynamic route control in accordance with the load situation, the flow entry is deleted and the route is recalculated sequentially. Therefore, the calculation cost on the OpenFlow controller in the route search is large and the packet throughput is reduced.

3. Proposed Method

3.1 *Overview*

In this study, we propose a multipath transmission method that reduces the amount of computation by distributing packets to multiple paths in accordance with the bandwidth ratio of the link. Furthermore, by using OpenFlow to control multiple routes at the appropriate timing considering real-time traffic, we also study the maximization of throughput in situations where congestion does not occur.

Fig. 2 shows an overview of the system. First, the OpenFlow controller obtains the network topology and the bandwidth of each router port. Next, the routing method adopts the optimal route on the basis of the single route control as the transmission route. However, as described above, multiple routes are controlled by the proposed method at appropriate timing. Appropriate timing refers to the situation where the bandwidth

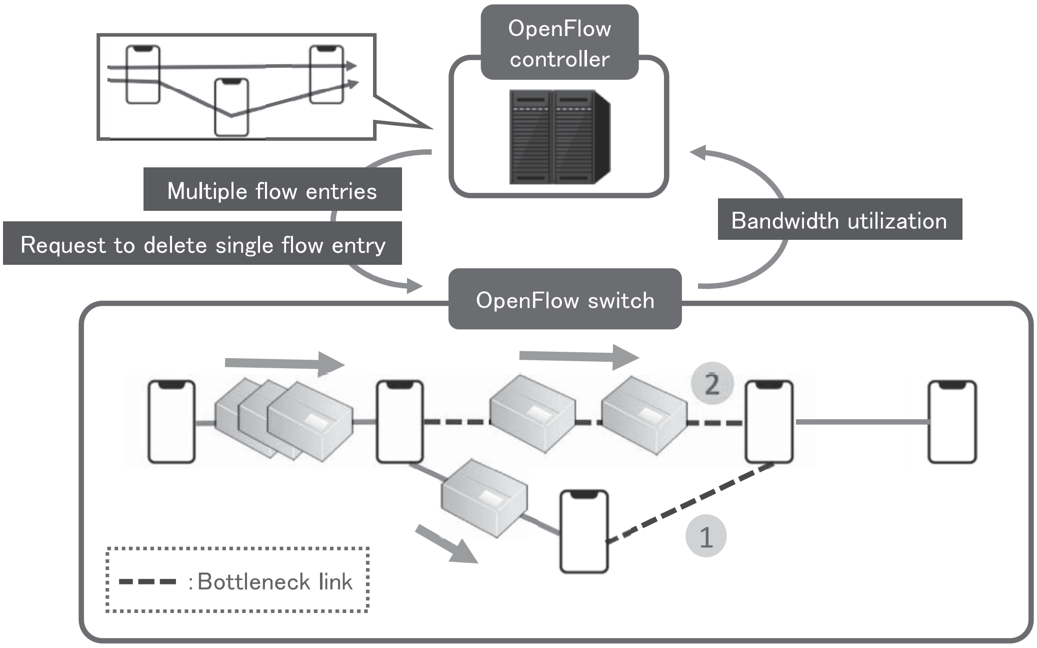

Fig. 2. System overview.

utilization rate of the bottleneck link on the optimal path in single path control is above the threshold. The bandwidth usage here is obtained by the OpenFlow controller inquiring to each router at regular time intervals.

Next, the method of multi-path control in the proposed method is described. When the bandwidth usage of the bottleneck link exceeds the threshold, the OpenFlow controller causes the router to discard the flow entry of the corresponding optimal route. After that, it calculates multiple routes to the destination and creates multiple flow entries. At this time, the flow entry is weighted in accordance with the bandwidth ratio of the bottleneck link of each route. In this way, multiple routes are controlled in accordance with the bandwidth ratio.

3.2 *Openflow controller*

The OpenFlow controller in this study has the following functions.

- Route storage
  The route information calculated by the optimal route control and multiple route control is cached in the OpenFlow controller to avoid recalculation when switching routes.
- Optimal routing control
  In response to a packet transfer destination inquiry from a router, the optimal route that minimizes the cost of the route to the destination is searched for and the flow entry is returned.
- Query bandwidth usage
  Calculate multiple routes. After that, the group table and the flow entry weighted in accordance with the bandwidth ratio of the bottleneck link of each route are returned.

3.3 *Operation procedure*

The operation procedure of the proposed method is described below. Fig. 3 shows the sequence diagram. The numbers in the sequence diagram correspond to the numbers in the following operation procedure.

(1) The router requests the packet forwarding destination to the OpenFlow controller.

(2) The OpenFlow controller searches for the optimal route and sends a flow entry to the router.

(3) The OpenFlow controller requests the router to use the bandwidth of each link.

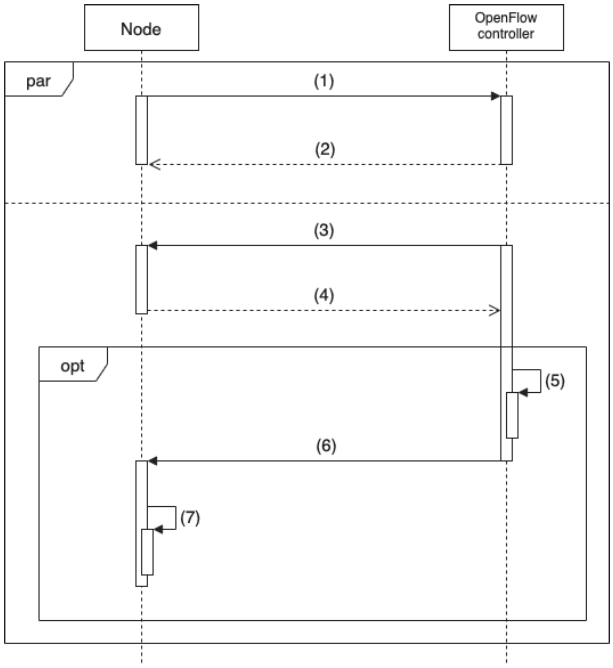

Fig. 3. Sequence diagram.

(4) The router sends the bandwidth usage of each link to the OpenFlow controller.

(5) If the bandwidth usage exceeds the threshold, the OpenFlow controller searches multiple routes.

(6) The OpenFlow controller deletes the flow entry and sends the group table and the flow entry to the router.

(7) The router deletes the flow entry of the optimal route and applies the received group table and flow entry.

4. Implementation

4.1 *Overview*

This study is implemented using ns-3.29[7], a discrete event network simulator. In addition, for the network load distribution according to the bandwidth ratio, the concept of flow entry grouping adopted from OpenFlow1.1 is used. One action is determined by using the selected type from multiple actions in the group entry. Action refers to the process of sending to each sending port in router multi-path control. When this action is selected, the network load distribution of the proposed method is realized by setting the bandwidth ratio of each bottleneck link of multiple paths as the weight.

4.2 *OFSWITCH13*

In this study, we use OFSWITCH13[8] which is provided as open source as an extension library of ns-3. This library provides controllers and switches for implementing the OpenFlow 1.3 protocol on ns-3. The following describes the modules used for bandwidth acquisition and packet load distribution.

- Bandwidth acquisition method
  A multi-part framework is used to obtain the port information of each switch from OpenFlow 1.3. When the OpenFlow controller requests the OFPMP_PORT_DESC type as a multipart request, the port information belonging to the OpenFlow switch is returned as a response. As a result, the port information in the multipart reply packet is obtained by the HandleMultipartReply handler of OFSWITCH13, and the bandwidth information of each port of the switch is obtained.
- Network load balancing method
  Multiple routes are calculated from the source and destination IP addresses by the Dijkstra method. Next, after caching the route to the OpenFlow controller, a group entry is created using the CreateGroupMod method of OFSWITCH13 is created. At this time, the type of the group entry is selected. Finally, a flow entry is created with the group ID of the group entry created earlier using the CreateFlowMod method of OFSWITCH13.

4.3 *Scenario environment*

In this experiment, large-capacity data communication is assumed. The evaluation scenario and its components are shown in Fig. 4 and Table 1, respectively. The topology of the evaluation scenario uses the Fat-Tree network configuration that is currently adopted as the topology

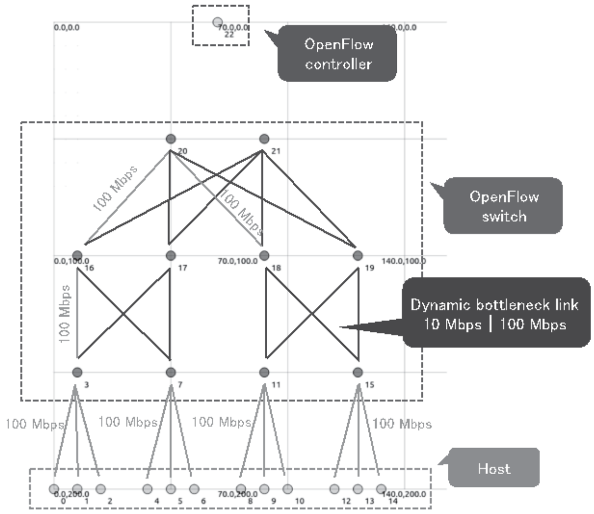

Fig. 4. Evaluation scenario.

Table 1. Scenario components.

OpenFlow controller	1
OpenFlow switch	10
Host	12
Link bandwidth	10Mbps, 100Mbps
Simulation time	10s

configuration of many mobile neworks[9]. As for the link bandwidth, the cost value of the link in a bandwidth of 100 Mbps or more is 1 due to the OSPF cost calculation. Therefore, two bandwidths of 10 and 100 Mbps were adopted. Traffic was generated from node 0 and host 2 to node 13 and from node 8 and host 10 to node 5 and its host. The content of the traffic uses a UDP (User Datagram Protocol) packet of 1460 bytes, whose payload per packet is the maximum value of MSS (Maximum Segment Size). Furthermore, the bandwidth of some links on the topology is changed to 10 Mbps and 100 Mbps.

5. Evaluation

5.1 *Overview*

OSPF, which is still widely used, is selected for comparison. OSPF in this paper refers to OSPFv2, which performs routing using

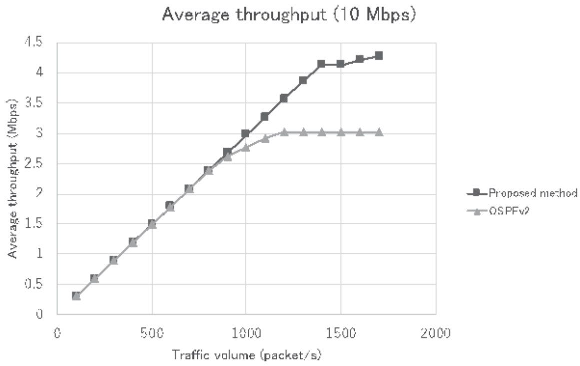

Fig. 5. Average throughput(10 Mbps).

OSPF-ECMP (Equal-Cost Multipath)[10]. The comparison items are the average throughput and the average packet loss rate for the traffic volume per unit time. As for packet generation, the number of packets generated per second varies between 100 and 1700. "Average throughput" and "average packet loss rate" are the average of the throughput and packet loss rate for each communication described in section 4.3. Furthermore, the bandwidth of the bottleneck link of the optimal route is changed to 10 and 100 Mbps, and two patterns are evaluated. This is to investigate whether the difference in the bandwidth ratio affects the evaluation results when performing the load distribution in accordance with the bandwidth ratio of the bottleneck link.

5.2 *Performance evaluation*

- Throughput

  Fig. 5 shows a graph of the average throughput when the bottleneck link is 10 Mbps. The proposed method has a maximum throughput about 1.3 that of OSPF. From this, the proposed method can clearly utilize the performance of the whole network more effectively than OSPF. Next, Fig. 6 shows a graph of the average throughput when the bottleneck link is 100 Mbps. Results show that the bottleneck link is almost the same as the average throughput at 10 Mbps.

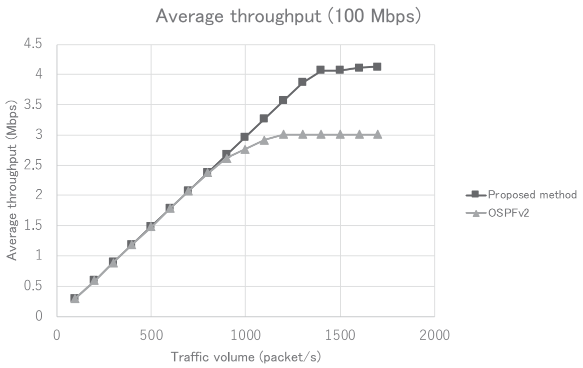

Fig. 6. Average throughput(100 Mbps).

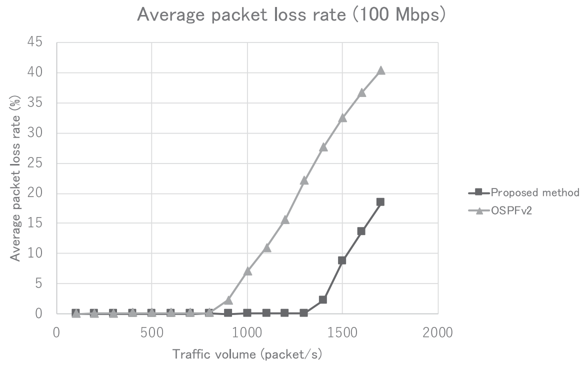

Fig. 8. Average packet loss rate(100 Mbps).

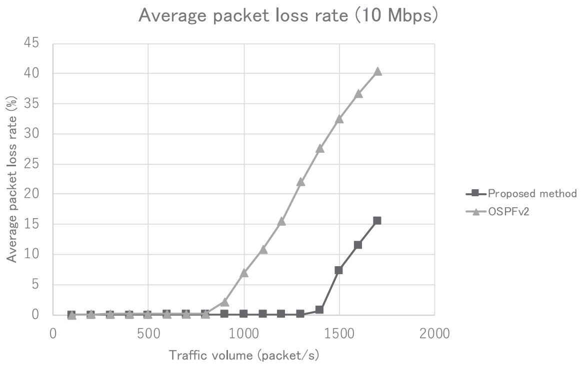

Fig. 7. Average packet loss rate(10 Mbps).

- Packet loss rate

  Fig. 7 shows a graph of the average packet loss rate when the bottleneck link is 10 Mbps. The proposed method has a lower loss rate at every packet generation rate than OSPF. This is because the number of packets that can be stored in the network has increased because the proposed method utilizes redundant routes. Next, Fig. 8 shows a graph of the average packet loss rate when the bottleneck link is 100 Mbps. The bottleneck link is almost the same as the average packet loss rate at 10 Mbps.

6. Consideration

In the proposed method, network load distribution using redundant routes is performed. On the other hand, in OSPF, load distribution is performed on routes with equal cost values to the destination node, but basically single route control is performed on the optimal route. In other words, the number of routers used is larger than that of the existing method. In this experiment, we observed that the proposed method performs routing using routers at nodes 17, 19, and 21 efficiently. As a result, it can be estimated that the capacity that can buffer packets in the whole network is larger than that of existing methods. Therefore, the packet loss rate decreases. Furthermore, it is considered that the router operates efficiently and the throughput is improved. Furthermore, even if the bandwidth of the bottleneck link on the optimal route is changed to 10 times, there is almost no change compared with the performance of the proposed method before the change. From this, it is considered that the network performance can be efficiently derived by the static load distribution in accordance with the bandwidth ratio.

Fig. 9 shows the packet loss rate during communication at each node when the traffic volume is 1000 packets/s. In OSPF, the loss rate of the packet transmitted from the host of nodes 8 and 10 is high. Compared with the packet loss rate of the other source nodes, the reachability of the packets transmitted by the host of nodes 8 and 10 is low. This is because packets transmitted from nodes farther from the router that is the bottleneck are more likely to be lost. In this experiment, the router

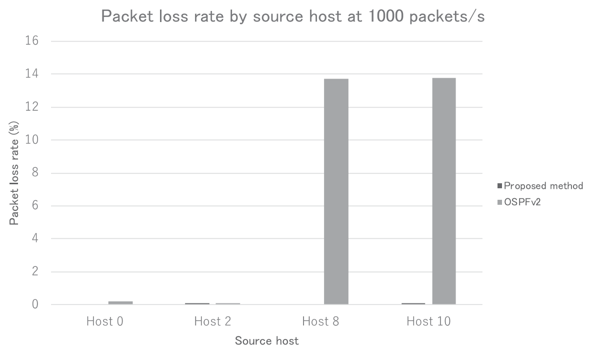

Fig. 9. Packet loss rate by sending host(1000 packets/s).

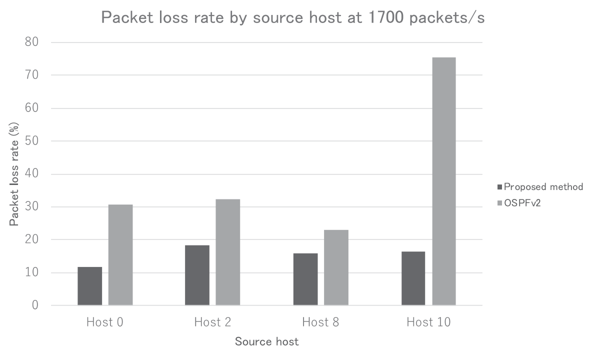

Fig. 10. Packet loss rate by sending host(1700 packets/s).

of node 20 becomes a bottleneck. The cost value from node 0 and host 2 to node 20 is 3, while the cost value from node 8 and host 10 to node 20 is 12. In other words, the packets transmitted from the host of nodes 0 and 2 have a higher possibility of being buffered by the router of node 20 than the packets transmitted from the hosts of nodes 8 and 10. Therefore, hosts 0 and 2 are considered to have lower packet loss rates and higher packet arrival rates than hosts 8 and host 10.

Fig. 10 shows the packet loss rate at the time of communication of each node when the traffic volume is 1700 packets /s. In the proposed method, there is no large difference in the transmission packet loss rate of each node, and the transmission packets of all nodes reach the destination node uniformly.

7. Conclusion

The recent increase of network traffic increases the risk of congestion in existing routing protocols. To solve this problem, a dynamic route control method using multiple routes was previously proposed, but it is not practical in terms of computational cost. In this study, we formed a hybrid network using OpenFlow and realized flexible routing. In addition, load distribution using multiple paths is statically performed in accordance with the link bandwidth ratio instead of dynamic, so that computational cost is reduced and throughput is improved. As a result of comparing the proposed method and OSPF, the proposed method was shown to have superior throughput and packet loss rate. Furthermore, it is considered that the routing by the proposed method is less likely to bias the packet arrival rate for each host.

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