# First Demonstration of Cross-domain Real-time Control between Networks and Computing Resources Utilizing Cooperative SLA Analysis

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**Abstract** To satisfy stringent requirements of low- and stable-latency applications, we propose a realtime cooperation scheme of optical network and computing resource controls. Experimental results demonstrated automatic path and resource switching can be performed within 63 milliseconds as a result of the novel cross-domain analysis function. ©2023 The Author(s)

### Introduction

Network advancements have improved user experiences by enabling network-based control for future remote services. We previously introduced a concept of remote drone control for inspecting and repairing facilities that enables dispatch-less operation [1]. As the working population in developed countries is decreasing [2], it is essential to improve operation efficiency.

To achieve remote inspection and repair via drones, low latency and high capacity are required in end-to-end communication. Low latency will enable operators to control drones with precise, complex movements, while high capacity will enable immersive, real-time video streaming to avoid missing any repair locations, as if operators were there in person. In addition to the high-quality transport network, edge computing [3] also plays a key role in deploying service applications that support operators, such as intelligent video image processing. Thus, endto-end communication quality (E2E quality) must take optical, mobile networks, and edge computing into consideration.

There have been several studies on orchestrating across networks and computing resources (domains) to ensure E2E quality. However, while the automation of resource management for delay-sensitive services has been reported [4-5], its real-time control characteristics is in the order of seconds [4]. Because a drone's control cycle is generally around 100 ms [6], further improvement is necessary to ensure stable operation for precise inspection and repair operations. The fast-control protocol [7] in single-digit milliseconds and fastresponse optical switches [8] in nano seconds have been reported. Therefore, the target of the real-time control can be derived to be less than 90 ms for the processing time in controllers.

We previously proposed a concept and possible solutions for a real-time control technique that is aware of service-level agreements (SLAs) and operates across optical and mobile networks [1]. We then verified its feasibility through an experimental study, in which automatic optical path control could be performed in less than 90 ms [9].

In this paper, we expand its scope to incorporate the optical network and computing resources. Specifically, we propose a crossdomain real-time control scheme cooperating between the optical network and computing resources, and we evaluate its real-time control characteristics.

# Cross-domain real-time control scheme cooperating between optical network and computing resources

Fig. 1 shows a typical architecture for remote drone control with a cross-domain real-time control scheme between an optical network and computing resources. We assume the Innovative Optical and Wireless Network (IOWN) All-Photonic Network (APN) [10] as the optical network because it potentially has low latency due to the elimination of OEO conversion at each interconnect node. The APN controller (APN-C) and computing resource controller (CR-C) collect guality information and control their resources to and from their domain resources, i.e., APN gateways (APN-Gs) and edge computing resources (CRs), respectively. We assume two or more candidates for edge CRs and optical paths



Fig. 1: Typical architecture for remote drone control with cross-domain real-time control scheme.



Fig. 2: Proposed flow of cross-domain real-time control scheme.

from an endpoint (APN transceiver (APN-T) at base station side) to the other endpoint (APN-T at operating system side). The controllers cooperatively analyse the E2E quality, and when the SLA is likely to be violated, they find and control switching to a new combination of resources.

Fig. 2 shows the detailed flow of the proposed scheme, which comprises three parts: collection, analysis, and control.

In the collection part, the controllers collect latency quality information from each resource (0-1). The quality info of computing resources is notified to the APN-C (2) so that the APN-C can analyse the E2E quality in the following part. This part is performed asynchronously and parallelly with other two parts. Streaming telemetry [11] is used to collect information quickly.

In the analysis part, the APN-C performs as a primary function with support from the CR-C. First, it is evaluated whether the E2E quality satisfies the target quality. E2E quality is calculated as the sum of the latency quality information from each domain, while the target quality is derived from an SLA for a service with a preconfigured margin. When the calculated quality exceeds the target, the APN-C tries to find another candidate within its domain. If it cannot find a candidate that satisfies the target quality, then it requests CR-C to find a new candidate within the computing resource domain (3). CR-C finds new candidates for the computing resource that can improve a

target value indicated within the request, and it responds to the APN-C with their quality info (4). Then the APN-C re-evaluates the E2E quality of the received candidates with the corresponding optical path quality and selects a new combination. The selected resource is finally verified by the CR-C (5-6) and then forwarded to the control part. Note that the APN-C and CR-C need to share the topology information of optical paths and edge CRs, which is preconfigured to each controller in the proposed scheme.

In the control part, both controllers trigger the switch to the new resources (7-10). The proposed scheme controls each resource simultaneously, which reduces the total processing time. An open data model such as OpenConfig [12] or Open ROADM [13] is used to control APN-Gs rather than a vendor-native model due to its cost effectiveness and interoperability.

#### Experimental setup

To determine the proposed scheme's feasibility, we extended the APN-C of our previous work [9] and developed the novel CR-C that supports the cross-domain real-time control scheme based on commercial products. An experimental validation of the processing times in the controller was conducted. Fig. 3 shows the experimental setup.

A general-purpose server with a Xeon E-2286G CPU with 32 GB RAM was used for the APN-C, and one with a Xeon E5-2670 v3 CPU with 32 GB RAM for the CR-C. White-box switches were used to simulate the APN-T and part of the APN-G. A fibre-cross-connect-based optical switch was used but was not essential for this study. We used one switch to simulate two logical switches by statically separating the port usage. For the endpoint application, we implemented a client server to access the web server periodically. The compute servers were used as a proxy server between client and web servers. Within each compute server, a function was implemented to measure processing time by calculating the difference between ingress and egress of the data packet. We changed the number of background processes in the compute servers to simulate the utilization of the edge CR, which causes time (latency) variation. We assumed two paths with corresponding edge



Fig. 3: Experimental setup for the feasibility study.

CRs, one which is activated, and one which is the candidate.

The experimental conditional differed from the proposed flow as follows: (1) We measured the latency quality of APN in advance because the latency in APN does not vary (i.e., omitted (0) in Fig. 2). (2) To create the open data model in the control part, we chose the OpenConfig data model as an example; however, it was converted to a vendor-native model afterwards because the optical switch used in the experiment did not support open data models. (3) A hot standby configuration was applied to switch computing resources quickly, which means the procedures at control part of the computing resource ((9-10) in Fig. 2) were omitted, to attain a total switching time of less than 90 ms.

## Performance evaluation and discussion

Using the experimental setup described above, we evaluated the processing times for the crossdomain real-time control scheme. We evaluated the processing times of each function and then determined the overall processing time with the fabricated setup.

Tab. 1 shows the detailed processing times of the proposed scheme. The times were measured by calculating the time difference of each message flow shown in Fig.2. The maximum processing time of 63 ms demonstrates that the proposed scheme is sufficiently faster than our target processing time (90 ms). Nevertheless, there is potential to further reduce the processing time. For instance, the evaluation periodicity at the APN-C, which was 10 ms in the experiment, can be shortened. In addition, an optical switch that supports open data models can be used to reduce the conversion time to a vendor-native model, which occupied almost 40% of the trigger optical path switch processing time.

Fig. 4 shows the E2E latency measured as the round-trip time between the client and web servers, as a function of elapsed time. The measurement of E2E latency was conducted per 10 ms and the number of background processes

in the activated edge CR was increased in the evaluation. We determined that once the E2E latency exceeds the threshold for the evaluation (50 ms), the optical path could be switched autonomously. The overall switching time including path switch execution at the APN-G observed from the 10 ms-period measured latencies was 856 ms, which is a reasonable result derived from Tab. 1. The majority of the overall switching time is the path switching at the APN-G, which will be resolved by applying the fast-control protocol [6] and fast-response switches [7].

# Conclusion

We have proposed a cross-domain real-time control scheme cooperating between an optical network and computing resources. In the proposed scheme, the optical network controller and the computing resource controller cooperatively analyse the E2E quality and switch the optical path and the resources in parallel to satisfy the stringent requirements of low- and stable-latency services such as remote drone control. The evaluation results demonstrated that the proposed scheme can perform the collection, analysis, and control within nearly 63 ms, which is sufficiently fast for remote drone control.



Fig. 4: E2E latency as a function of elapsed time across optical path and computing resources switching.

Processing			Processing time [ms]		
Span	Description	Node	Min.	Avg.	Max.
-(1)	Measurement of quality	Edge CR	0.18	0.21	0.26
(1)–(2)	Notification APN-C of quality	CR-C	1.61	1.88	2.38
(2)–(3)	Evaluation and search of optical path	APN-C	9.84	11.07	13.31
(3)–(4)	Search of computing resource	CR-C	9.48	10.88	12.20
(4)–(5)	Re-evaluation	APN-C	2.50	3.93	7.94
(5)–(6)	Confirmation	CR-C	1.52	1.80	1.90
(6)–(7)	Trigger optical path switch	APN-C	3.23	8.85	25.12
Summary			28.36	38.62	63.11
(7)–(8)	(Ref.) Path switch execution	APN-G	679.93	716.68	789.98

Tab. 1: Processing time for cross-domain real-time control scheme. Numbers in "Span" correspond to Fig. 2.

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