SLA-aware Real-time Control Technology for All Photonics Network and Beyond (Invited)

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***Abstract*— The paper introduces SLA-aware real-time control technology that we proposed for establishment of low-latency services over all photonics networks and beyond. Key features of agile collection, analysis, and control functions and technical issues are reviewed.**

Keywords—Real-time control, All photonics network

I. INTRODUCTION

As the percentage of the working-age population in developed countries has been decreasing annually [1], network operators are required to efficiently provide network services with a reduced workforce. To address this issue, remote services, such as remote robotics surgery and remote drone inspection over a network, are promising solutions because a network operator does not need to dispatch doctors or technicians to each location even in rural or hard-to-reach areas. However, such a service requires a network to provide a large bandwidth for 4K/8K live-streaming video signals and low latency for remote control operation [2, 3].

We previously proposed and investigated Service Level Agreement (SLA)-aware real-time control technology for establishing services that require large bandwidth and low latency over the All Photonics Network (APN) and beyond [4-6]. In this paper, we review the key features of this technology, including its controller architecture, and discuss its technical issues.

II. ALL PHOTONICS NETWORK

There are a few networks that can provide high bandwidth and low latency; 5G and time-sensitive networks are good examples [7, 8]. However, an APN meets these requirements since it can offer an end-to-end optical direct connection without Optical-to-Electrical-to-Optical (O/E/O) conversion at each node. Although the concept of the APN is not new, its potential as a future network infrastructure is currently drawing attention. Fig. 1 shows a schematic view of the APN

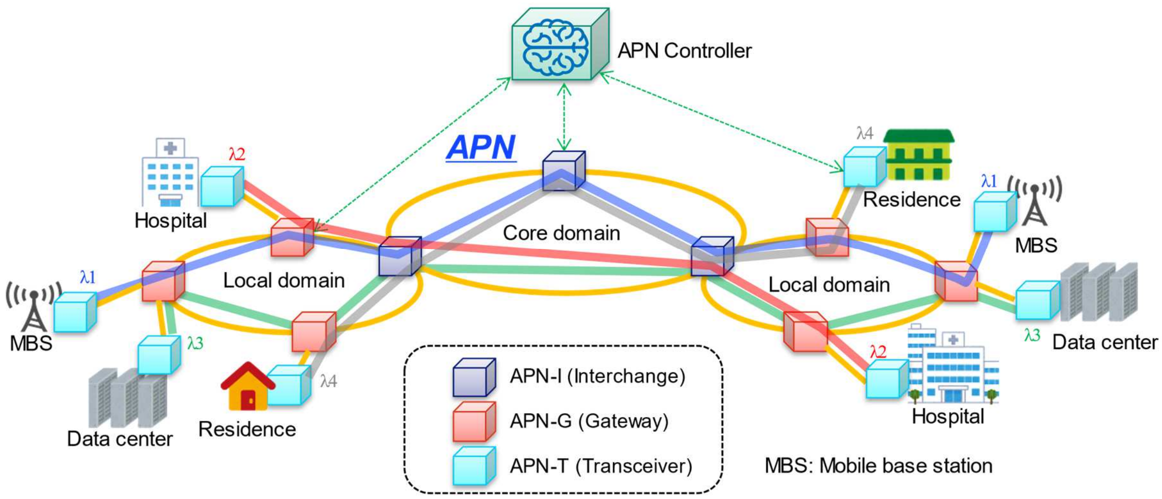


Fig. 1 Schematic view of All Photonics Network.

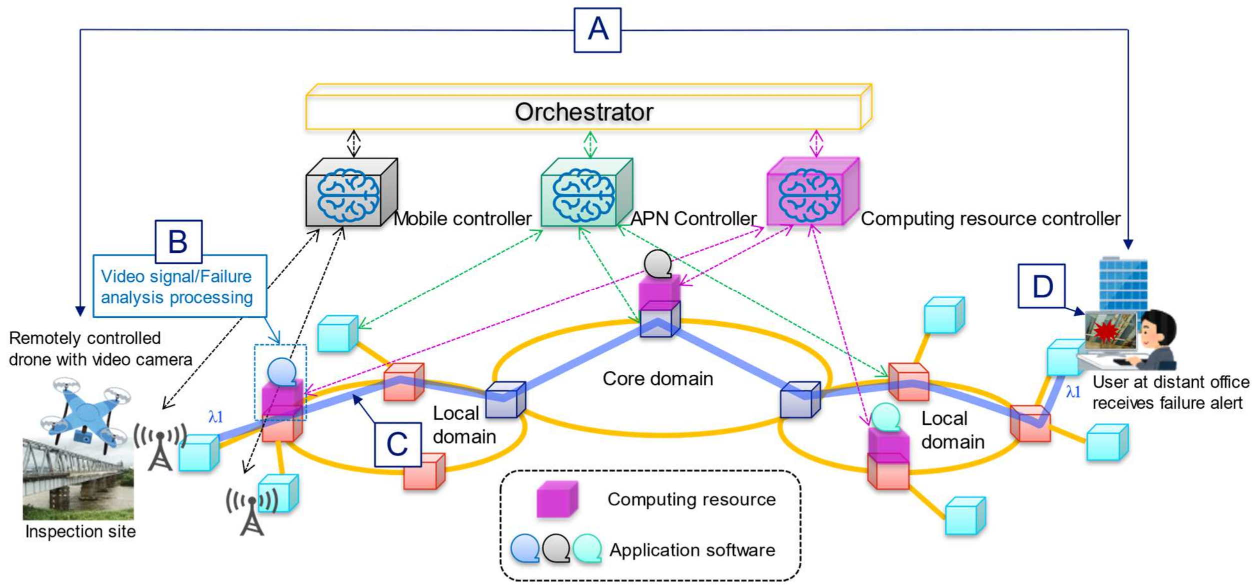
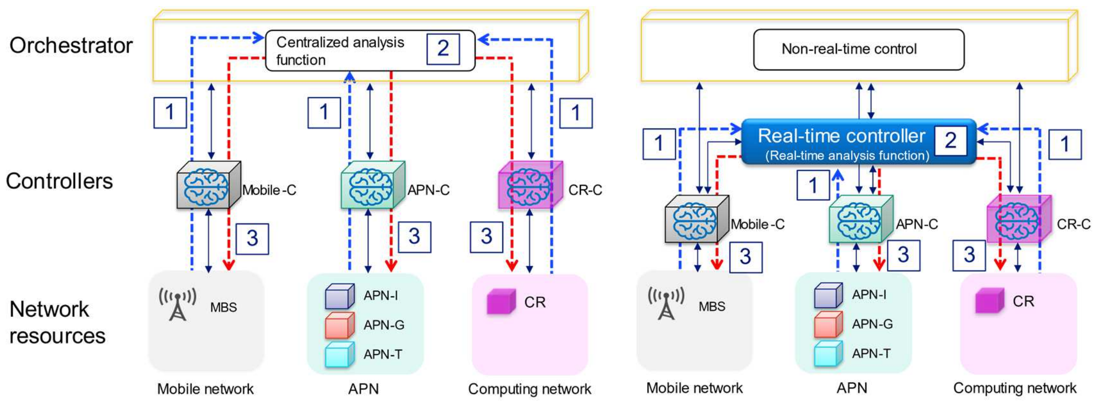


Fig. 2 Remote-inspection service by drone across APN, computing resources, and mobile networks.

that we are intensively developing under the framework of the IOWN Global Forum [9]. The APN consists of optical fibers, optical nodes of interchanges (APN-Is), and gateways (APN-Gs) for the core and local domain, respectively, and transceivers (APN-Ts) as endpoints of the optical path. The APN-Is and APN-Gs function as an optical aggregation and router for each domain, and no O/E/O conversions occur there, unlike conventional networks. Therefore, we can expect large bandwidth and low latency. As shown in Fig. 1, we assume that the APN will be shared by multiple users and services as a common platform and be managed and controlled by the APN controller (APN-C). For example, optical path and wavelength are assigned by the APN-C.

III. COLLABORATION AMONG APN, COMPUTING RESOURCES, AND MOBILE NETOWORKS

In addition to the APN, which is a powerful enabler for emerging services, certain services require electrical processing at computing resources even though they need O/E/O conversion and inter-working with mobile networks. As shown in Fig. 2, the remote-inspection service by drone requires collaborative operation with computing resources at an edge and application software that offers video signal processing and failure recognition. Collaboration with mobile networks to provide wireless signal transmission between a drone and a mobile base station (MBS) is also necessary. Fig. 2 also shows an assumed procedure for remote inspection using collaboration among the APN, computing resources, and mobile networks. (A) A drone equipped with a 4K/8K video camera is remotely operated from the user's office and flies around a bridge to collect video for inspection of each section of the bridge. (B) Streaming video signals from the drone are transmitted to an MBS via air, and an APN-T converts the signals to optical signals for transmission over the APN. The optical signals are then transmitted to a computing resource (CR) through an APN-G. The application software (video signal processing and failure recognition) running on the CR analyses the signals to find a failure section of the bridge. (C) Whenever it recognizes a



(a) Conventional architecture (b) Proposed architecture for real-time control

Fig. 3 Architectures for cross-domain real-time control scheme.

failure, the software immediately sends a notification signal with related video data over the APN to a user at a distant office (APN-T). (D) The user receives the notification signals as an alert and can determine the condition/location of a failure in real time. Therefore, an on-site drone pilot is not needed.

However, remote drone inspection requires stringent end-to-end (E2E) latency of 100 ms or less, including processing time of the video signals and failure recognition at the CR [10]. Since various services other than inspection will be provided on the same platform, all network resources should be shared among the services. Therefore, if congestion occurs at the resources, how to maintain 100-ms latency during the service should be addressed.

IV. Proposed Architecture of SLA-Aware Real-Time Control Technology Across Multiple Domains

To meet a stringent requirement of E2E latency of 100 ms or less, we recently proposed and investigated SLA-aware real-time control technology [4-6]. In the multi-domain network composed of the APN, CRs, and mobile networks, as shown in Fig. 2, each network resource is continuously monitored by each controller and comprehensively analyzed. The controller(s) dynamically switches network resource(s) if SLA is likely to be violated. To achieve this, we need to consider what the architecture for the cross-domain control scheme should look like.

Fig. 3 (a) shows the conventional architecture for the cross-domain control scheme. The architecture is hierarchically composed of an orchestrator, domain controllers, and network resources. The orchestrator has a centralized analysis function for comprehensive analysis among multiple domains. The procedure mainly consists of three steps (1) collection, (2) analysis, and (3) control; the details of each step are as follows. (1) The orchestrator periodically acquires network-quality information from each controller. (2) The orchestrator analyses on the basis of SLA and decides to switch network resources if SLA is likely to be violated. The orchestrator sends a request for resource switching to the relevant controller(s). (3) Each domain controller accordingly controls the resource(s) for switching.

Although the above procedure based on the conventional architecture for cross-domain control is straightforward, it seems difficult to achieve in-service dynamic switching at 100 ms or less because the procedure requires a second order for processing via an orchestrator [11].

Fig. 3 (b) shows the proposed architecture for the cross-domain real-time control. We locate the real-time controller, responsible for comprehensive analysis across multiple domains in real-time, close to the domain controllers rather than inside an orchestrator. The detailed procedure is as follows. (1) The real-time controller periodically and quickly acquires network-quality information from each controller. (2) The controller analyses on the basis of SLA and decides to switch network resources if SLA is likely to be violated. Upon decision, the controller quickly sends a request for resource switching to the relevant domain controller(s). (3) Each

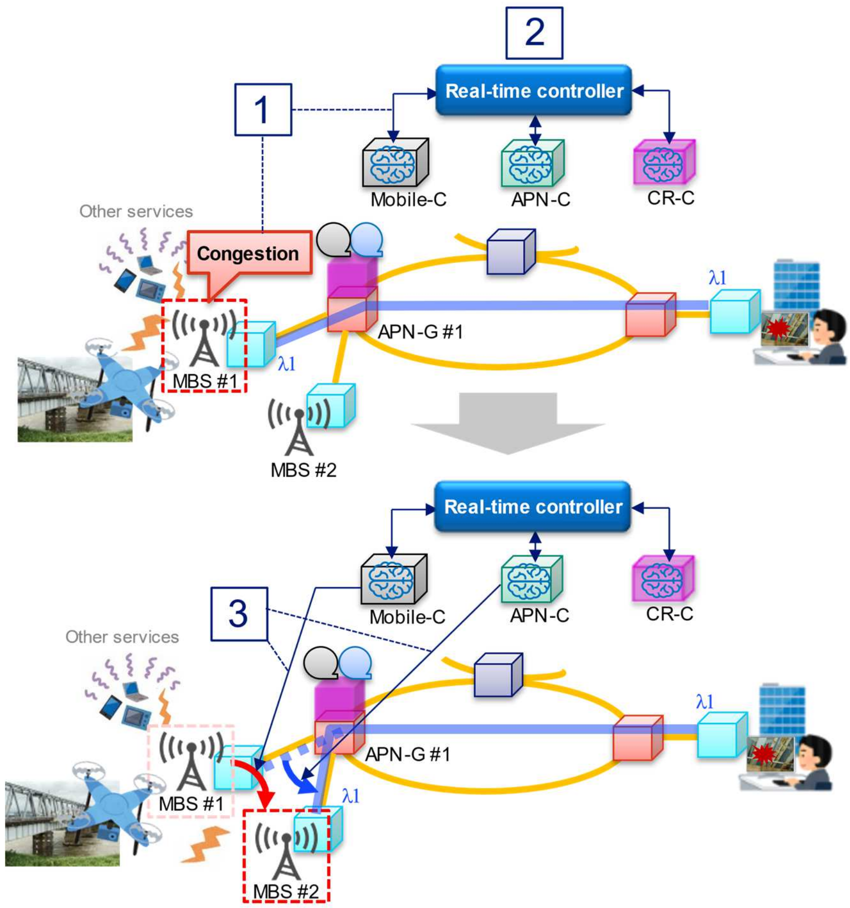


Fig. 4 Example of using SLA-aware real-time control technology when there is congestion at MBS.

domain controller accordingly controls the resource(s) for switching.

Thanks to the real-time controller, the proposed architecture is advantageous for in-service dynamic control of network resources in multiple domains.

Fig. 4 shows an example how SLA is maintained during the remote-inspection service by drone using the proposed technology. In this example, we assume MBS #1 (APN-T) and the user at the distant office is connected by wavelength #1 (λ1) via APN-G #1. If congestion occurs at MBS #1, the procedure of the SLA-aware real-time control scheme is as follows. (1) Each domain controller periodically collects network-quality information (e.g., traffic volume at MBSs, processing time at CRs, optical power variation in the APN) and sends it to the real-time controller. (2) On the basis of the collected information, the controller continuously analyses whether the network qualities satisfy the latency requirement (SLA). When the controller recognizes SLA is likely to be violated due to congestion at MBS #1 caused by other services, it attempts to find other available MBSs then decides to switch the traffic of the inspection service from MBS #1 to MBS #2. The controller then directs MBS switching to Mobile-C and optical-path switching to APN-C. (3) Mobile-C and APN-C immediately execute resource switching, in accordance with the decision at the controller. Thus, the user and uncongested MBS #2 is connected by the new optical path of λ1, and SLA is successfully maintained during the service.

Thanks to the real-time collection-analysis-control procedure, a multi-domain network could maintain 100-ms latency during the remote drone inspection service.

V. TECHNICAL ISSUES

Based on the proposed architecture, we recently succeeded in dynamic optical path switching using the real-time controller, which provides comprehensive analysis across optical and mobile networks [9]. We achieved a total processing time of less than 20 ms at the real-time controller, which was a successful result as the preliminary study. However, this means that other procedures (e.g., telemetry and optical path switching) should be completed within 80 ms, but this is left for further study. Furthermore, the following technical issues but not limited to should be addressed

- Streaming telemetry: Short-period telemetry (e.g., 10-ms period) via open interfaces (e.g., OpenConfig, Open ROADM) is necessary for fast information collection from network resources and interoperability.
- Optical-path switching: Fast optical-path switching including command processing time (e.g., <10 ms) via open interfaces with lightweight encoding is necessary for fast optical path control and interoperability.

To promote interoperability among network and infrastructure providers who organize each domain controller, definitions of high-speed interfaces as an international standard between the real-time controller and domain controllers are necessary.

VI. CONLUSIONS

Our recently proposed SLA-aware real-time control technology over the APN in cooperation with computing resources and mobile networks was introduced. A real-time controller that provides comprehensive analysis across multiple domains plays is vital for establishing this technology. Although there are a few technical issues, our proposed technology is promising for future latency-critical services in a reduced workforce era.

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