Demonstration of QoS-Aware Video Streaming over a Metro-Scale Optical Network Using a Cross-Layer Architectural Design

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Abstract: QoS-aware video streaming is demonstrated on an optical network using a service-oriented architecture and a NetFPGA-based optical control plane. Dynamic optical power fluctuations are either compensated or the lightpath is rerouted to ensure the QoS.
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1. Introduction

The layered architecture of the current Internet is becoming increasingly strained in supporting the ever-increasing number of users and applications [1-5]. Today's optical networks assume a highly reliable physical layer with low bit-error rates (BERs) through over-provisioning of the network capacity [6]. As the bandwidths carried by these optical channels increase, the traditional manner of over-provisioned optical transport capacity may no longer be economically feasible. Meeting the exponentially growing bandwidth demands of emerging applications requires a dynamically reconfigurable optical layer that can function in unison with the upper networking layers.

Many emerging applications will require innovative ways to support video streaming, which is predicted to account for more than 90% of consumer IP traffic by 2014 [7]. Some of these new video applications, such as telemedicine and teleconferencing, will require much more stringent quality-of-service (QoS) guarantees than those offered today, while other applications may have more tolerant reliability constraints. Video streaming has previously been demonstrated over various optical network architectures [8]. Furthermore, impairment-aware traffic engineering [6] and QoS-aware packet protection mechanisms [9,10] have also been shown on experimental optical test-beds [11]. However, no work as of yet has shown an integrated cross-layer communication platform involving all networking layers that demonstrates the advantages of using physical-layer impairment compensation and QoS-awareness to stream videos through an optical network.

In this work, we experimentally demonstrate a video streaming application across the Breakable Experimental Network (BEN) [12], a metro-scale optical test-bed located in North Carolina. We add cross-layer communication and control capabilities to BEN by integrating it with the SILO [2] service-oriented architecture and a NetFPGA-based optical control plane (OCP). Dynamic optical power fluctuations introduced to BEN are either compensated using a semiconductor optical amplifier (SOA) or the lightpath is rerouted to ensure that a video requiring high QoS retains its fidelity. For comparison, a video requiring lower QoS is transmitted without impairment compensation or rerouting and suffers a noticeable degradation in quality.

2. Metro-Scale Optical Testbed: BEN

BEN connects together four point-of-presences (PoPs) in a bidirectional ring topology: University of North Carolina at Chapel Hill (UNC), Duke University, North Carolina State University (NCSU), and the Renaissance Computing Institute (RENCI). BEN allows researchers to have unrestricted access to all networking layers, from physical layer to the application layer. Each PoP shares the same network architecture consisting of a Polatis switch on the physical layer, an Infinera Digital Transport Node (DTN) that provides circuit-oriented connections up to 10 Gb/s per wavelength, a Cisco 6509 that provides reconfigurable switching/routing capability for finer granularity access to the bandwidth on the IP layer, and a cluster of IBM Blade servers tied together with a Juniper EX3200 switch. The accessibility of BEN's network layers makes it a suitable platform to explore cross-layer network architectures.

3. SILO Architectural Framework

SILO [2] (Fig. 1) is a flexible, service-oriented architecture designed to explore the future Internet. A service is a well-defined and self-contained function performed on application data. A specific implementation of a service is called a method *m*, and a stack of methods form a silo. Methods are selected dynamically for a particular application, but not all methods can be assumed to be able to coexist with each other on the same silo. The order in which methods are applied is not tied to any specific layer, but rather to a set of well-defined precedence constraints, called the ontology. The silo and service management module uses the ontology information to manage the ordering and constraints of methods to assemble silos. Further, each method contains control parameters, called knobs, which can be adjusted based on feedback from the knobs of other methods to optimize the performance of the application or the host. The cross-service tuning module manages this knob-tuning capability with a set of predefined strategies.

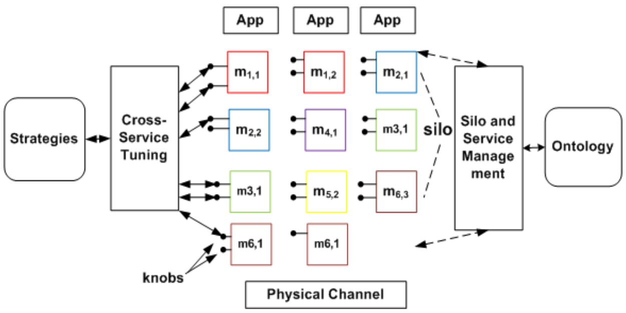

Fig. 1. The SILO architectural framework.

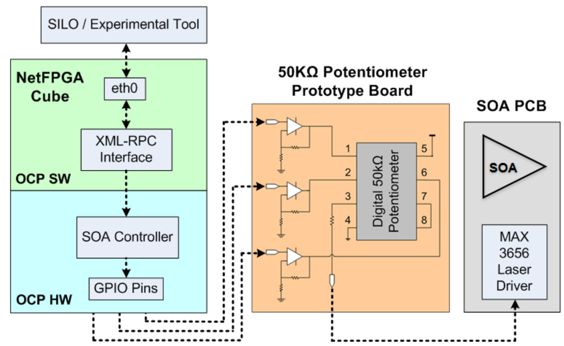

Fig. 2. NetFPGA-based OCP enables cross-layer communication between the optical layer and higher network layers.

4. NetFPGA-Based Optical Control Plane

The OCP (Fig. 2) is implemented on a NetFPGA Cube system, which is composed of a general purpose processor and the NetFPGA hardware. The OCP software component (OCP SW) enables higher-layer protocols and networking equipments to communicate with the optical layer. In this experiment, we use Extensible Markup Language-based (XML) remote procedure call (RPC) protocol to interface with the higher layer services defined by SILO. More specifically, SILO services can use these predefined XML-RPC calls to control a SOA. Furthermore, the NetFPGA-based OCP hardware component (OCP HW) provides the flexibility to actuate a variety of devices in the optical layer. In this experiment, the OCP HW consists of an SOA controller that can control the gain of a SOA. The SOA resides on a printed circuit board (PCB) that contains a MAX 3656 laser driver. The amount of current driven by the laser driver, which controls the SOA's gain, is further controlled by a 50-kΩ digital potentiometer that is housed on a prototype board. The SOA Controller uses a set of general purpose input/output (GPIO) pins on the NetFPGA to control the gain of the SOA based on the XML-RPC commands directed from the OCP SW.

5. Experimental Demonstration and Results

Fig. 3 shows how SILO and the OCP are integrated into BEN to demonstrate QoS-aware video streaming from the UNC PoP to the RENCI PoP. The OCP is integrated into the physical layer of BEN between the UNC and RENCI PoPs, sharing the same lightpath as the Polatis switches. Also inserted into the same lightpath is a variable optical attenuator (VOA), which is used to introduce a controlled power fluctuation via a Matlab script.

At the UNC PoP, a video source is streamed through the SILO Application Gateway, which wraps the video stream packets into SILO packets and forwards them through four SILO services. The packet dropping service can selectively drop packets, and it is not used at the transmitter (UNC PoP). The measurement collector service on the transmitter side retrieves optical power from specified ports on the Polatis switches through an Extensible Messaging and Presence Protocol (XMPP) Publish-Subscribe (PubSub) server. Based on the measured power, the SOA controller service regulates the amplification of the SOA via the OCP to compensate for the power loss due to the VOA and to stabilize the port power. If the power fluctuation is greater than the 11 dB that the SOA can compensate for, the interface switch service switches the output from the SOA-protected path through Eth0 to an alternative path through Eth1. Note that all video packets pass through the four SILO services, but the power compensation mechanisms are deactivated for videos requiring a low QoS.

As the video packets are transmitted to the RENCI PoP, they first pass through the Infinera DTN, which applies forward error correction (FEC) on the incoming packets to correct errors introduced by physical-layer impairments. Using FEC, the DTN ensures that the video packets will either be error-free, or it will enter a failure state with the lightpath shutdown. For the sake of the demonstration, we need to ensure that the lightpath does not shut down due to power fluctuations, and BEN continuously streams the video regardless of the signal degradation. To achieve this, we ensure that the VOA does not introduce a power fluctuation of more than 25 dB. Then, the measurement collector service on the RENCI side retrieves the pre-FEC BER of the incoming packets from the DTN, and the packet dropping service drops a percentage of received video packets proportional to the pre-FEC BER.

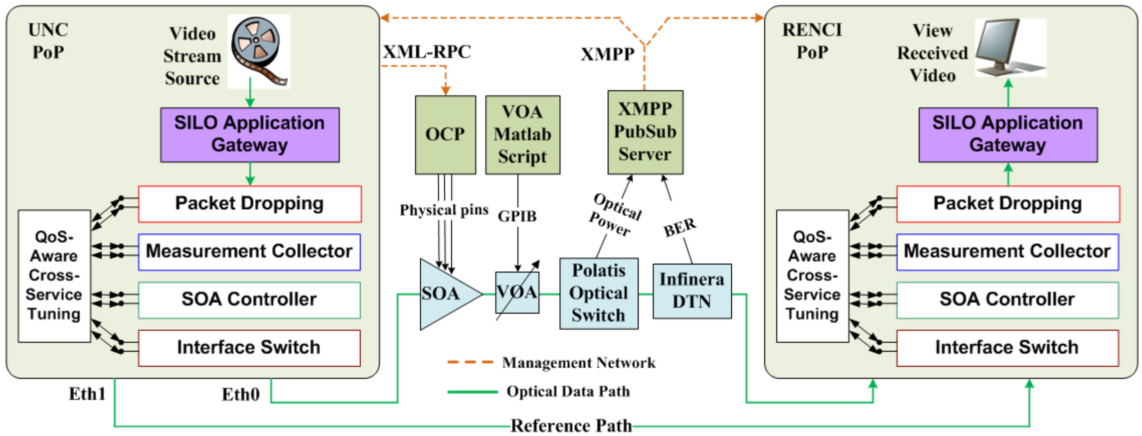

Fig. 3. Integration of SILO and OCP into BEN to enable QoS-aware video streaming.

Fig. 4(a) shows the received power level of a video requiring low QoS, which has power compensation deactivated. The full range of power fluctuation is 10 dB (between -7 to -17 dBm). Fig. 4(b) shows the received power level of a video with a higher QoS requirement. In this case, the power fluctuation is ensured to fall within 3 dB (between -10 to -13 dBm). Fig. 5(a) shows a screenshot of a noticeably degraded video requiring low QoS, while Fig. 5(b) shows a screenshot of a video requiring a higher QoS, which shows no degradation.

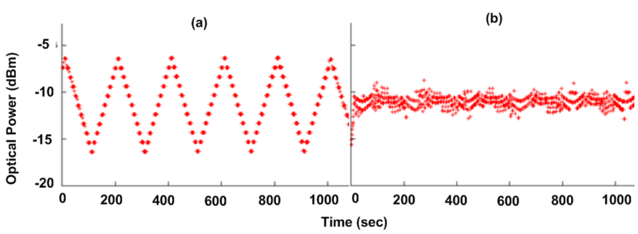

Fig. 4. Measured optical power on SOA-protected path of video requiring (a) low QoS and (b) high QoS.

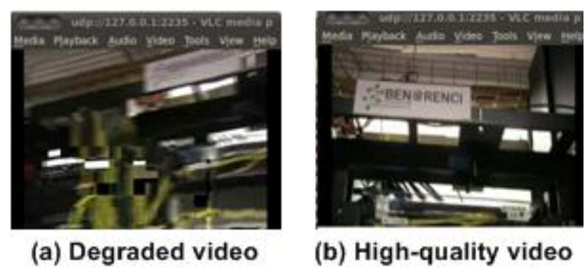

Fig. 5. Screenshots of (a) degraded video requiring low QoS and (b) video requiring high QoS with protection mechanism enabled.

5. Conclusions

QoS-aware video streaming is demonstrated over BEN using the SILO service-oriented architecture and a NetFPGA-based optical control plane. When optical power fluctuations are introduced in the network, videos that require higher QoS retain their fidelity through optical power compensation or lightpath rerouting. This demonstration uses optical-power-aware routing as an example to highlight the advantages of SILO and an optical control plane; this cross-layer architectural design can be further extended to other types of network protection and restoration schemes.

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