

# Complete End-to-End Network Path Control for Scientific Communities with QoS Capabilities

Chin Guok (ESnet)

26th International Conference on Computing in  
High Energy & Nuclear Physics

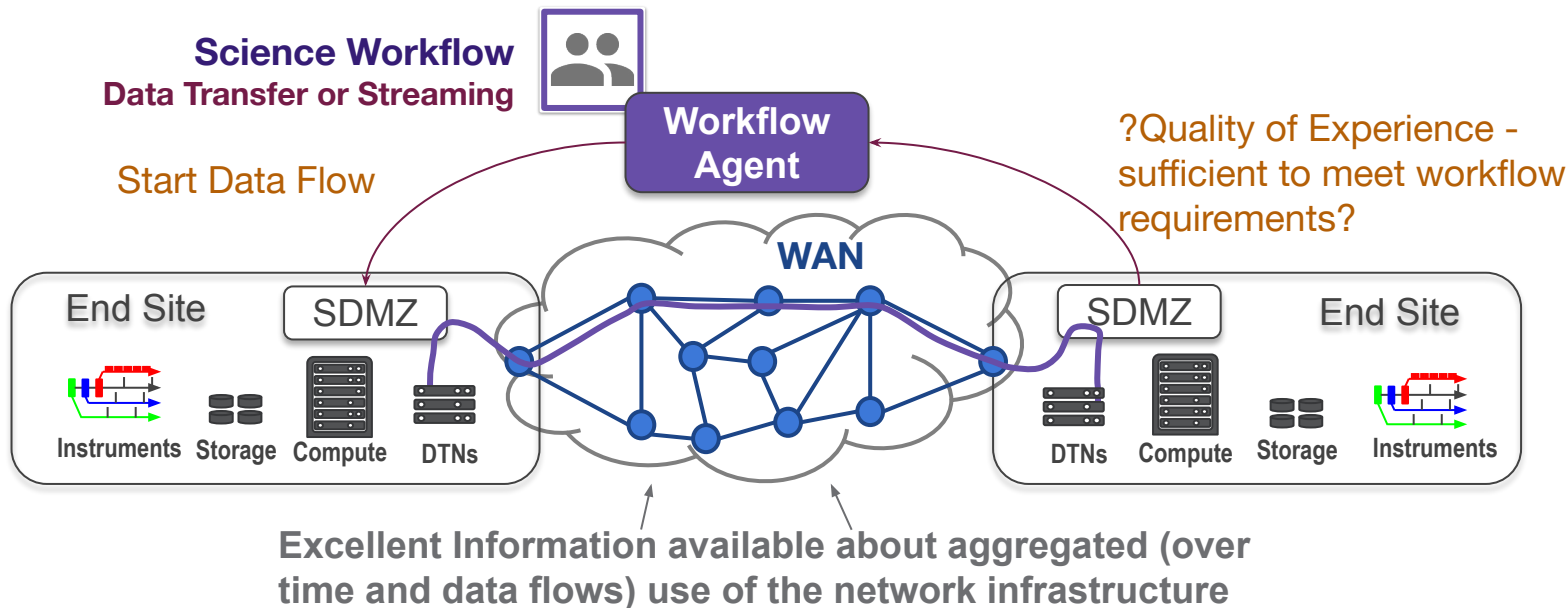
May 8 – 12, 2023  
Norfolk, Virginia



**ESnet**

# Enable Science Workflow and Network Interaction with Deterministic "Quality of Experience"

- No realtime per flow data available for planning or monitoring
- No "deterministic" network services available
- Start data flow, and hope for the best



# Elevate Network to First Class Resource

## API driven Automation and Orchestration

Science Workflow  
Data Transfer or Streaming



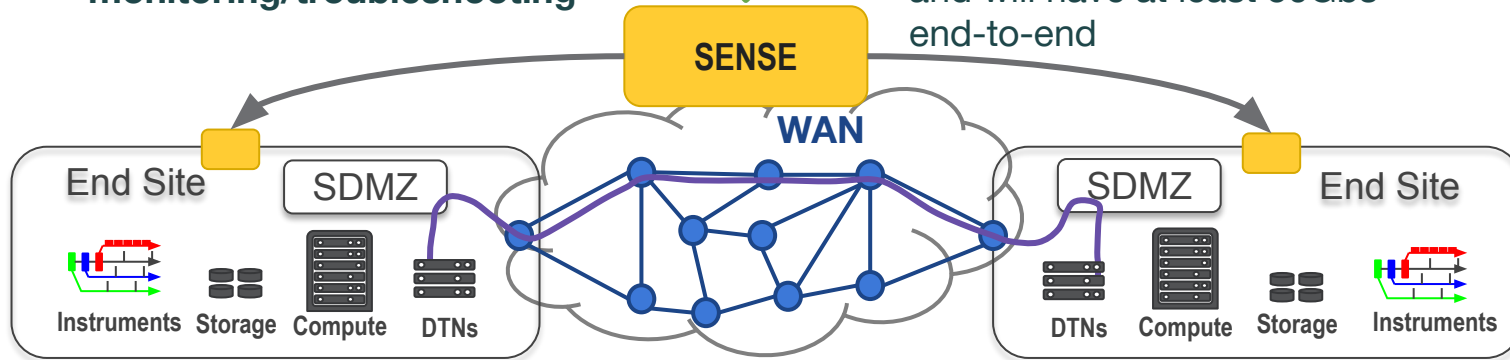
Workflow  
Agent

SENSE operates between science workflow and the distributed cyberinfrastructure

Workflow and Network can interact for planning, resource discovery, negotiation, and full life cycle monitoring/troubleshooting

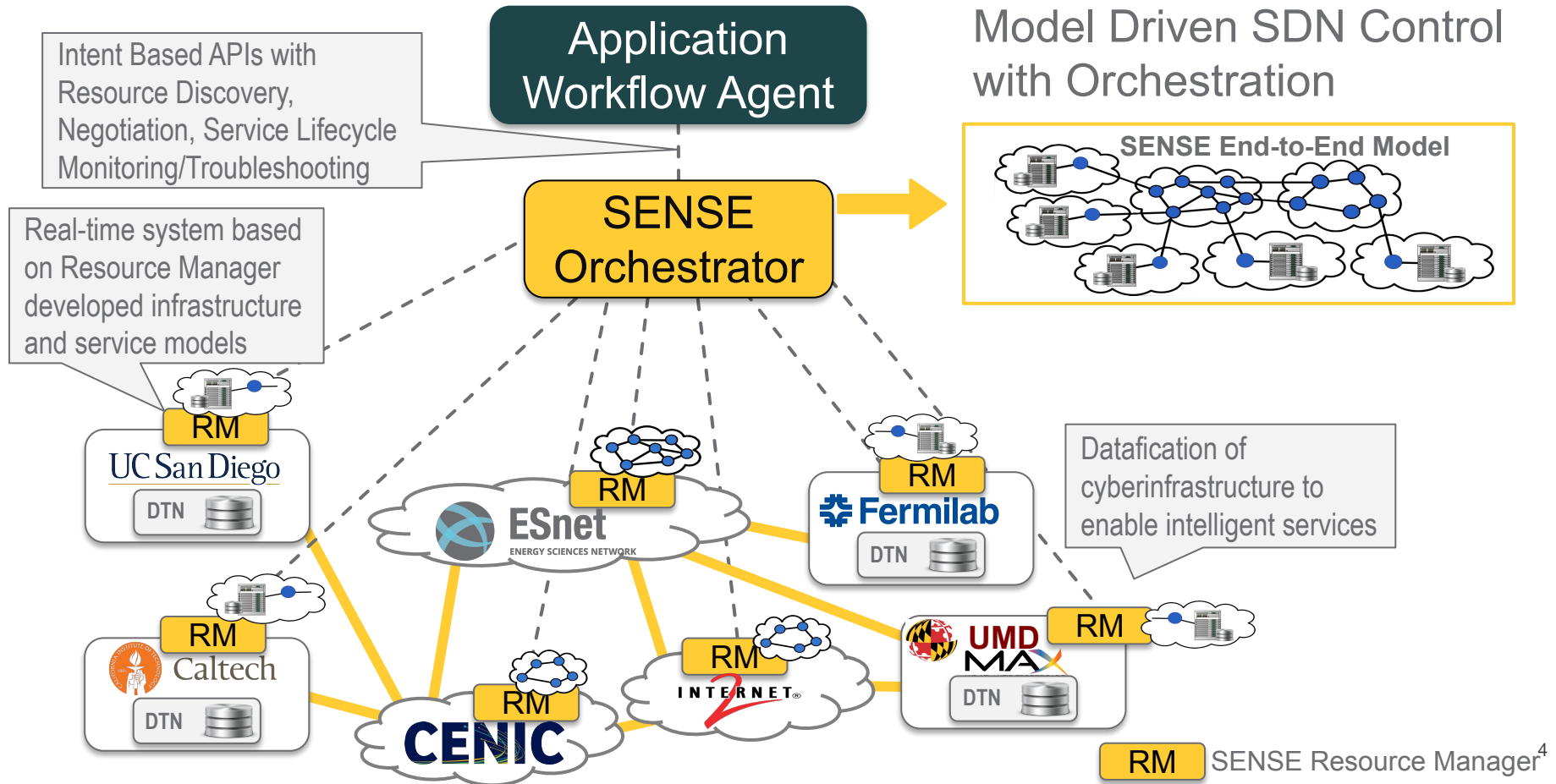
Workflow: Would like to move 1TB anytime in the next 24 hours

Network: You can start in 2 hours, and will have at least 50Gbps end-to-end



- Allows workflows to identify data flows which are higher priority
- Allows the network to traffic engineer to fully utilize all network paths

# SENSE Architecture

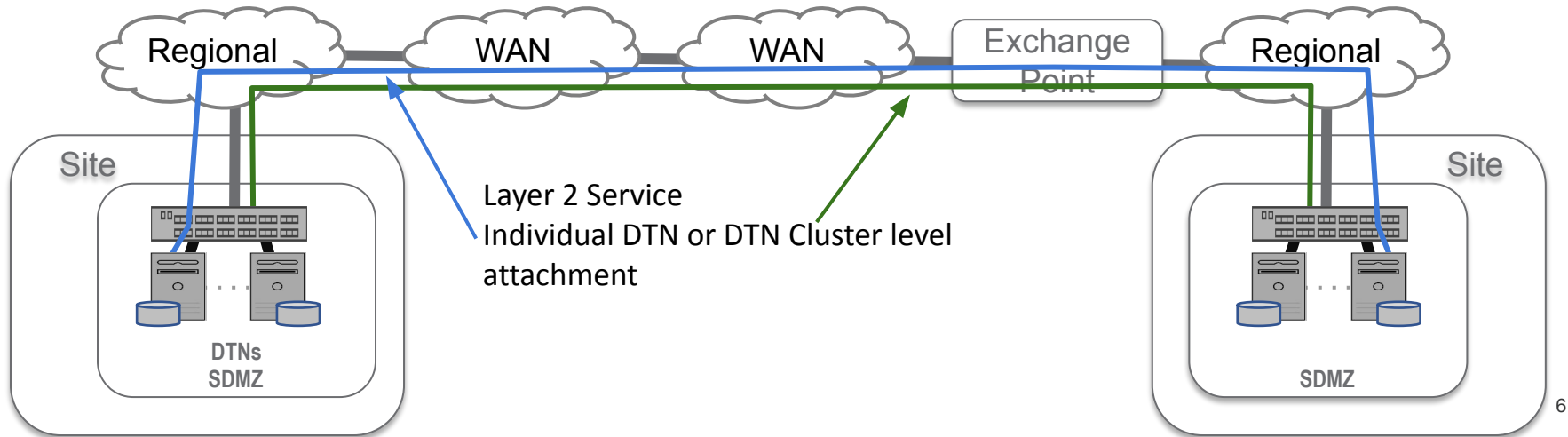


# SENSE Solution Approach – Application Interactions

- **Intent Based** – Abstract requests and questions in the context of the application objectives.
- **Interactive** – What is possible? What is recommended? Let's negotiate.
- **Real-time** – Resource availability, provisioning options, service status, troubleshooting.
- **End-to-End** – Multi-domain networks, end sites, and the network stack inside the end systems.
- **Full Service Lifecycle Interactions** – Continuous conversation between application and network for the service duration.

# SENSE Services

- Orchestration (of other domain owned systems)
- Multi-Resource (networks, end systems, instruments, clouds)
- Multi-Domain (Sites, Regionals, WANs, Exchange Points)
- Multi-Service (L2 Point-to-Point, L2 MultiPoint, L3VPN, QoS, Traffic engineered paths)
- Intelligent Services, realtime interaction, full-lifecycle monitoring



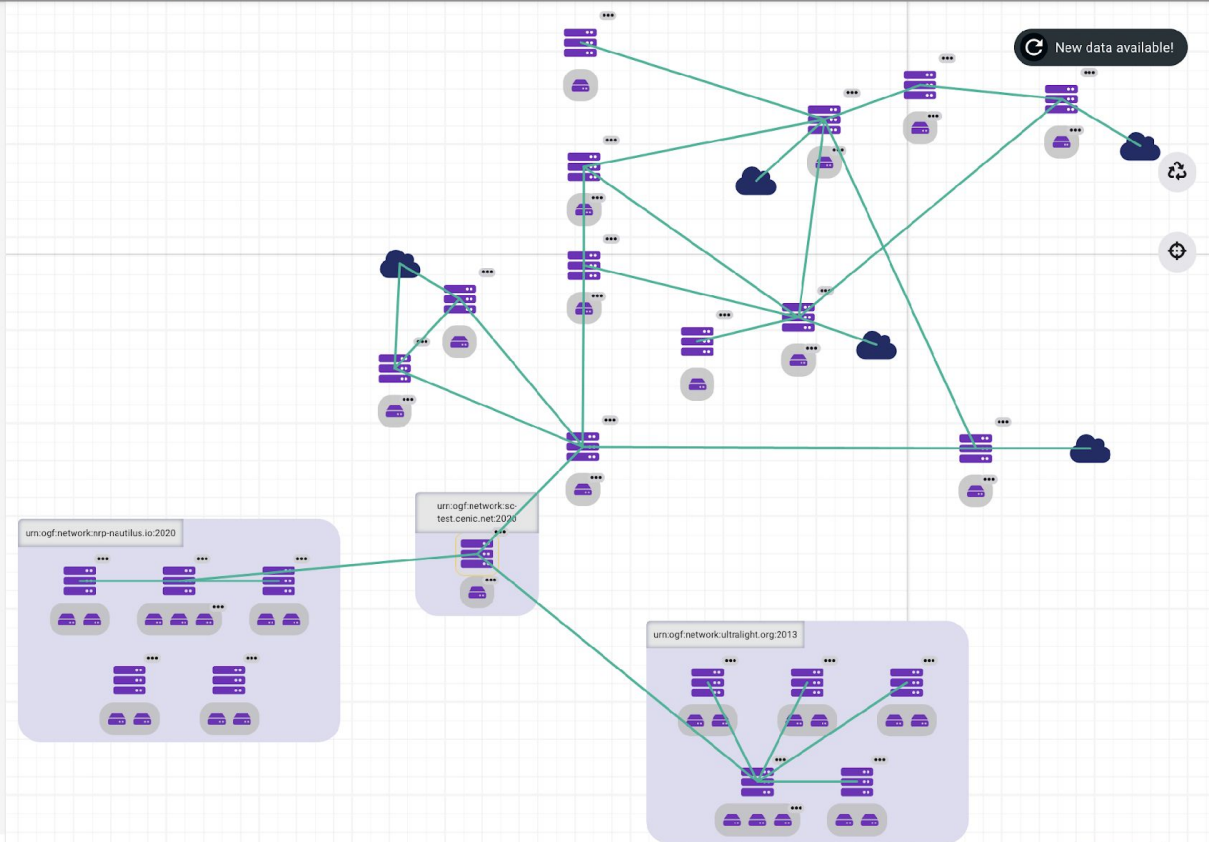
# SENSE - Model based Resource Descriptions

urn:ogf:network:sc-test.cenic.net:2020:aristaeos\_s0

PREVIOUS

NEXT

- hasBidirectionalPort (6)
- urn:ogf:network:sc-test.cenic.net:2020:aristaeos\_s0:Ethernet10-1
  - urn:ogf:network:sc-test.cenic.net:2020:aristaeos\_s0:Ethernet9-1
  - urn:ogf:network:sc-test.cenic.net:2020:aristaeos\_s0:Port-Channel501
  - urn:ogf:network:sc-test.cenic.net:2020:aristaeos\_s0:Port-Channel502
  - urn:ogf:network:sc-test.cenic.net:2020:aristaeos\_s0:Ethernet1-1



# SENSE Orchestrator - Service Template

- Read only and optionally with user editable parameters
- Allows user to run with one time "ticket" or multiple time-use allocations

### Service Template Example

Allocation and Editable VLAN Range

Licenses

tlehman - 3 slot(s) given.  
allocation

+

MAKE EDITABLE

Selected: DATA > CONNECTIONS > 0 > TERMINALS > 1 >

VLAN\_TAG

Validator (optional)

3987-3989

Use a list of comma-separated values, a numeric range, or a raw regex without slashes (ex. \*.uri.\*)

```
object ▶ data ▶ connections ▶ 0 ▶ terminals ▶ 1 ▶ vlan_tag
▼ DNC root schema {2}
  ▼ data {2}
    type : Multi-Path P2P VLAN
    ▼ connections [1]
      ▼ 0 {4}
        ▼ bandwidth {2}
          qos_class : guaranteedCapped
          capacity : 1000
        ▼ suggest_ip_range [1]
          ▼ 0 {2}
            start : 10.251.86.10/24
            end : 10.251.86.20/24
          name : Connection 1
        ▼ terminals [2]
          ▼ 0 {3}
            vlan_tag : any
            assign_ip : true
            uri : urn:ogf:network:calit2.optiputer.net:2020:k8s-gen4-01.calit2.optiputer.net
          ▼ 1 {3}
            vlan_tag : 3987
            assign_ip : true
            uri : urn:ogf:network:cern.ch:2013:cixp-surfnet-dtn.cern.ch
        service : dnc
```

JSON View    Alias



# SENSE - Site Layer 3 Flow to WAN Traffic Engineered Path Service

CATALOG    DETAILS    DRIVERS    VISUALIZATION    ADMIN    System Refresh On ✓    ACCOUNT    LOGOUT

DETAILS

VISUALIZATION

ADDONS

LOGGING

### ADDITION

urn:ogf.network:sc-test.cenic.net:2020:aristaeos\_s0

PREVIOUS    NEXT

*hasBidirectionalPort (2)*

- urn:ogf.network:sc-test.cenic.net:2020:aristaeos\_s0:Port-Channel501
- urn:ogf.network:sc-test.cenic.net:2020:aristaeos\_s0:Port-Channel502

Browser    Verification    Search

The diagram illustrates a network topology on a grid background. At the top center is a switch node labeled 'urn:ogf.network:sc-test.cenic.net:2020'. Below it are three server nodes: 'urn:ogf.network:ultralight.org:2013' on the left, 'urn:ogf.network:sc-test.cenic.net:2020' in the middle, and 'urn:ogf.network:mp-nautilus.io:2020' on the right. A green line connects the top switch to the left server. Blue lines connect the top switch to the middle server and the right server. The middle server is also connected to the right server. A refresh icon is visible on the right side of the diagram.

# SENSE - Northbound API



## Info



## Tags



## Servers



Search



### workflow\_combined ^

GET /profile

GET /profile/{uuid}

GET /instance

POST /instance/{siUUID}

DELETE /instance/{siUUID}

GET /instance/{siUUID}/status

PUT /instance/{siUUID}/{action}

GET /intent/instance/{siUUID}

### workflow\_phased ^

GET /profile

GET /profile/{uuid}

GET /instance

POST /instance/{siUUID}

DELETE /instance/{siUUID}

GET /instance/{siUUID}/status

Aa

SAVE

Read Only

```
1 openapi: 3.0.2
2 info:
3   version: 2.0.3
4   title: SENSE-O Northbound Intent API
5   description: StackV SENSE-O Northbound REST API Documentation
6
7 servers:
8   - url: "https://dev1.virnao.com:8443/StackV-web/restapi"
9
10 security:
11   - oAuth2Keycloak: []
12
13 tags:
14   - name: workflow_combined
15     description: |-
16       methods for single-phase workflows (minimal provisioning
17       steps)
18     `instance/{siUUID}/{action}` uses `provision`, `cancel`
19     and `repvovision` calls.
20
21   - name: workflow_phased
22     description: |-
23       methods for two-phase commit workflows (useful for co
24       -scheduling)
25     `instance/{siUUID}/{action}` uses `propagate`, `release`,
26     `reinststate` and `commit` calls.
27
28   - name: service
29     description: service workflow methods
30   - name: instance
31     description: Service instance methods
32   - name: profile
```

Last Saved: 8:18:31 pm - Feb 28, 2022

VALID

## SENSE-O Northbound Intent API

2.0.3 OAS3

StackV SENSE-O Northbound REST API Documentation

Servers

https://dev1.virnao.com:8443/StackV-we...

Authorize

### workflow\_combined

methods for single-phase workflows (minimal provisioning steps) `/instance/{siUUID}/{action}` uses `provision`, `cancel` and `repvovision` calls.

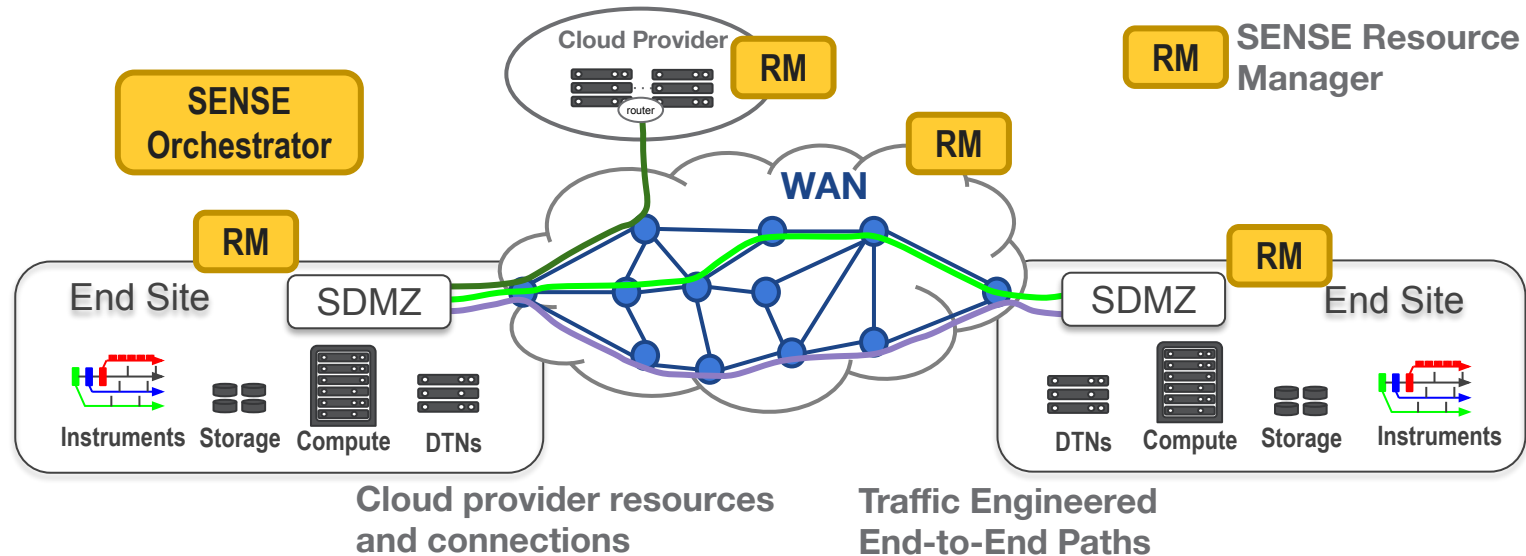
GET /profile Get skimmed profile data

GET /profile/{uuid} Get single profile

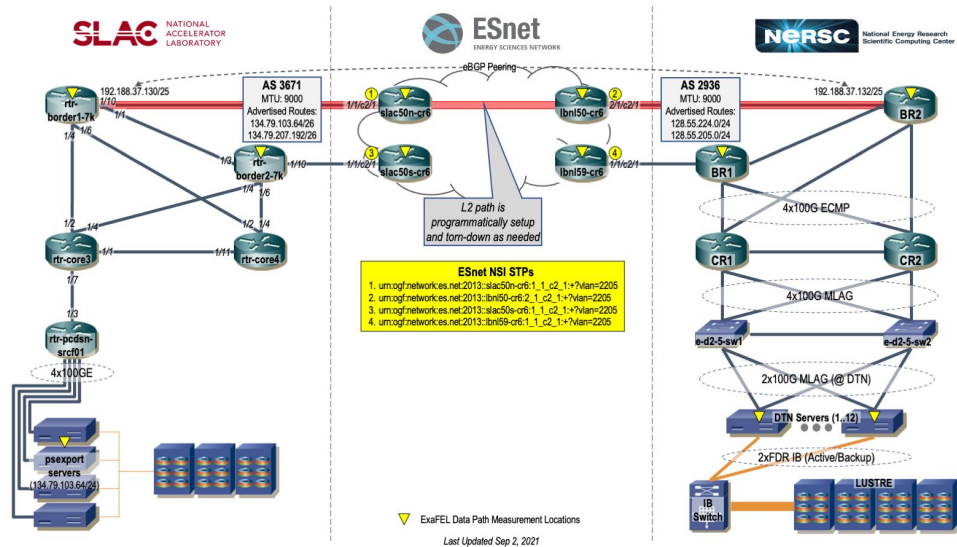
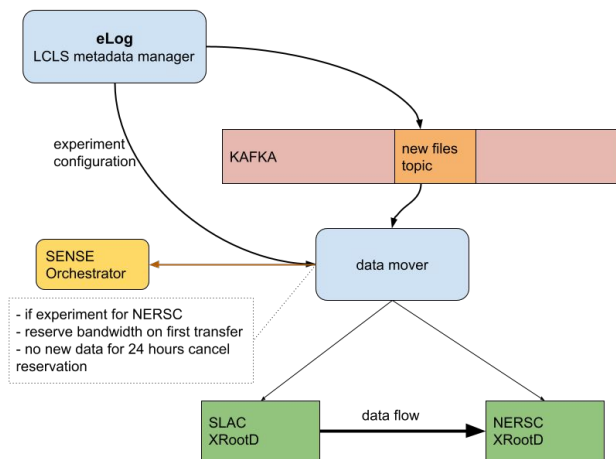
GET /instance Generate new service instance UUID

# Multi-Resource Orchestration

- Networks, End-Systems, Cloud Resources, Instruments
- No need to manage/orchestrate all of the resources end-to-end, just the ones that matter
  - congestion, performance, or policy reasons



# ExaFEL/SuperFacility SENSE Interoperation



## ExaFEL Last-Mile-WG Orchestration Report

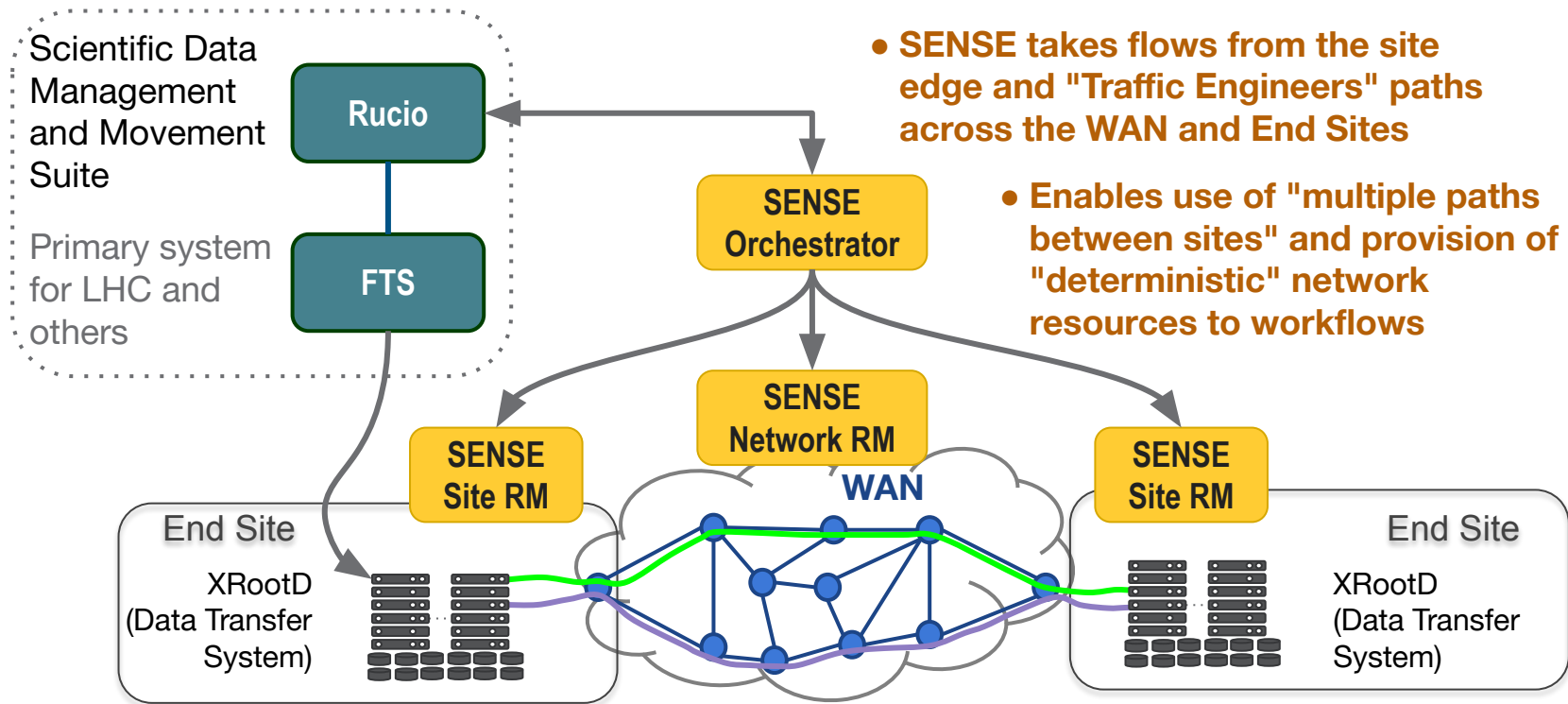
October, 2021

Wilko Kroeger<sup>†</sup>, Mark Foster<sup>†</sup>, Chin Guok<sup>Δ</sup>, Damian Hazen<sup>‡</sup>, Thomas Lehman<sup>Δ</sup>, Ashwin Prabhu Selvarajan<sup>‡</sup>, Alexander Sim<sup>◦</sup>, Xi Yang<sup>Δ</sup>

<sup>‡</sup>NERSC {dhazen, apselvarajan} @ lbl.gov, <sup>Δ</sup>ESnet {chin, tlehman, xiyang} @ es.net, <sup>†</sup>SLAC {fosterm, wilko} @ slac.stanford.edu, <sup>◦</sup>LBL {asim} @lbl.gov

# SENSE and Rucio/FTS/XRootD Interoperation

- Rucio identifies groups of data flows (IPv6 subnets) which are "high priority"



# SENSE Papers and Info

- Software-Defined Network for End-to-end Networked Science at the Exascale, Elsevier Future Generation Computer Systems, Volume 110, September 2020, Pages 181-201,

<https://doi.org/10.1016/j.future.2020.04.018>

– Accepted Manuscript:


<https://arxiv.org/abs/2004.05953>

- [SENSE Northbound API Program](#)

– <https://app.swaggerhub.com/apis/xi-yang/SENSE-O-Intent-API>

- SENSE Website

– [sense.es.net](https://sense.es.net)



Future Generation Computer Systems 110 (2020) 181–201

Contents lists available at ScienceDirect

Future Generation Computer Systems

journal homepage: [www.elsevier.com/locate/fgc](http://www.elsevier.com/locate/fgc)

Software-Defined Network for End-to-end Networked Science at the Exascale

Inder Monga<sup>a</sup>, Chin Guok<sup>a</sup>, John MacAuley<sup>a</sup>, Alex Sim<sup>a</sup>, Harvey Newman<sup>b</sup>, Justas Balcas<sup>c</sup>, Phil DeMar<sup>d</sup>, Linda Winkler<sup>e</sup>, Tom Lehman<sup>f</sup>, Xi Yang<sup>g\*</sup>

<sup>a</sup> Energy Sciences Network, Lawrence Berkeley National Lab, Berkeley, CA, USA  
<sup>b</sup> Division of Physics, Mathematics and Astronomy, Caltech, Pasadena, CA, USA  
<sup>c</sup> Computing Division, Fermi National Accelerator Laboratory, Batavia, IL, USA  
<sup>d</sup> Computing, Environment and Life Science Division, Argonne National Lab, Argonne, IL, USA  
<sup>e</sup> VMware, Arlington, VA, USA  
<sup>f</sup> IBM-Atlantic Crossroads, University of Maryland, College Park, MD, USA

**ARTICLE INFO**

**ABSTRACT**

**Article history:**  
Received 1 March 2019  
Received in revised form 26 February 2020  
Accepted 8 April 2020  
Available online 13 April 2020

**Keywords:**  
Intent based networking  
End-to-end orchestration  
Intelligent network services  
Distributed infrastructure  
Resource modeling  
Software defined networking  
Real-time  
Interactive

Domain science applications and workflow processes are currently forced to view the network as an opaque infrastructure into which they inject data and hope that it emerges at the destination with an acceptable Quality of Experience. There is little ability for applications to interact with the network to exchange information, negotiate performance parameters, discover expected performance metrics, or receive status/troubleshooting information in real time. The work presented here is motivated by a vision for a new smart network and smart application ecosystem that will provide a more deterministic and interactive environment for domain science workflows. The Software-Defined Network for End-to-end Networked Science at Exascale (SENSE) system includes a model-based architecture, implementation, and deployment which enables automated end-to-end network service instantiation across administrative domains. An intent based interface allows applications to express their high-level service requirements, an intelligent orchestrator and resource control systems allow for custom tailoring of scalability and real-time responsiveness based on individual application and infrastructure operator requirements. This allows the science applications to manage the network as a first-class schedulable resource as is the current practice for instruments, compute, and storage systems. Deployment and experiments on production networks and testbeds have validated SENSE functions and performance. Emulation based testing verified the scalability needed to support research and education infrastructures. Key contributions of this work include an architecture definition, reference implementation, and deployment. This provides the basis for further innovation of smart network services to accelerate scientific discovery in the era of big data, cloud computing, machine learning and artificial intelligence.

Published by Elsevier B.V.

**1. Introduction**

Networked systems are evolving at a rapid pace toward programmatic control, driven in large part by the application of software to networking concepts and technologies, and evolution of the network as a critical subsystem in global scale systems. This is of interest to major science collaborations that incorporate large scale distributed computing and storage subsystems.

This software-network innovation cycle is important as it includes a vision and promise for improved automated control, configuration, and operation of such systems, in contrast to the labor-intensive network deployments of today. However, even the most optimistic projections of software adoption and deployment do not put networks on a path that would make them behave as a truly smart or intelligent system from the application or user perspective, nor one capable of interfacing effectively with facilities supporting highly automated data analysis workflows at sites distributed around the world.

Today, domain science applications and workflows processes are forced to view the network as an opaque infrastructure into which they inject data and hope that it emerges at the destination with an acceptable Quality of Experience. There is little ability for

\* Corresponding author.  
E-mail addresses: [imonga@es.net](mailto:imonga@es.net) (I. Monga), [chin@es.net](mailto:chin@es.net) (C. Guok), [macauley@es.net](mailto:macauley@es.net) (J. MacAuley), [asim@sl.gov](mailto:asim@sl.gov) (A. Sim), [newman@physics.caltech.edu](mailto:newman@physics.caltech.edu) (H. Newman), [jbalcas@fnl.gov](mailto:jbalcas@fnl.gov) (J. Balcas), [demar@fnl.gov](mailto:demar@fnl.gov) (P. DeMar), [winkler@fnl.gov](mailto:winkler@fnl.gov) (L. Winkler), [lehman@uiowa.edu](mailto:lehman@uiowa.edu) (T. Lehman), [xiyang@um.edu](mailto:xiyang@um.edu) (X. Yang).

<https://doi.org/10.1016/j.future.2020.04.018>  
0167-7390/© published by Elsevier B.V.

# Acknowledgements



**ESnet**

Chin Guok, Tom Lehman,  
Inder Monga, Xi Yang



Harvey Newman, Justas Balcas, Preeti Bhat



Frank Würthwein, Jonathan Guiang, Aashay  
Arora, Diego Davila, John Graham, Dima Mishin,  
Thomas Hutton, Igor Sfiligoi



**Fermilab**

Oliver Gutsche, Phil Demar



# Thanks