NETS: JUNO2:
Resilient Edge Cloud Designed Network (RECN)

JUNO2 PI Final Meeting
August 18, 2021

T. Saadawi, M. Tsuru, K. Tsukamoto, A. Kawaguchi

Project Members

City University of New York, City College (CCNY), USA

Professors:

- Akira Kawaguchi (Co-PI)
- Myung Lee (Co-PI)
- Abbe Mowshowitz (Co-PI)
- Tarek Saadawi (PI)

Kyushu Institute of Technology (Kyutech), Japan

Professors:

- Takeshi Ikenaga
- Kenji Kawahara
- Kenichi Kourai
- Daiki Nobayashi
- Masahiro Shibata
- Kazuya Tsukamoto
- Masato Tsuru

* Names are in alphabetic order

Objectives

The objective of the RECN Group is to conduct between the two Institutions collaborative and foundational research on a resilient edge cloud designed network to achieve basic understanding of the underlying science for future RECN.

This work will cover issues of security, heterogeneity, resource constraints and potential mobility of end devices/sensors. A backbone network will be implemented and diversity of access network technologies, availability/placement of computing resources and Quality of Service (QoS) requirements will be examined.

The RECN Group will focus on two key challenges:

1) **Architecture, Resource access, virtualized adaptable computing and networking, network security, and distributed database using hypercube, (first 4 tasks).**
2) **Real-life Experimentation, emulation and simulation of large scale Internet of Things (IoT) with application to smart grid (this is highlighted in the "Testbed Experiments" section)**

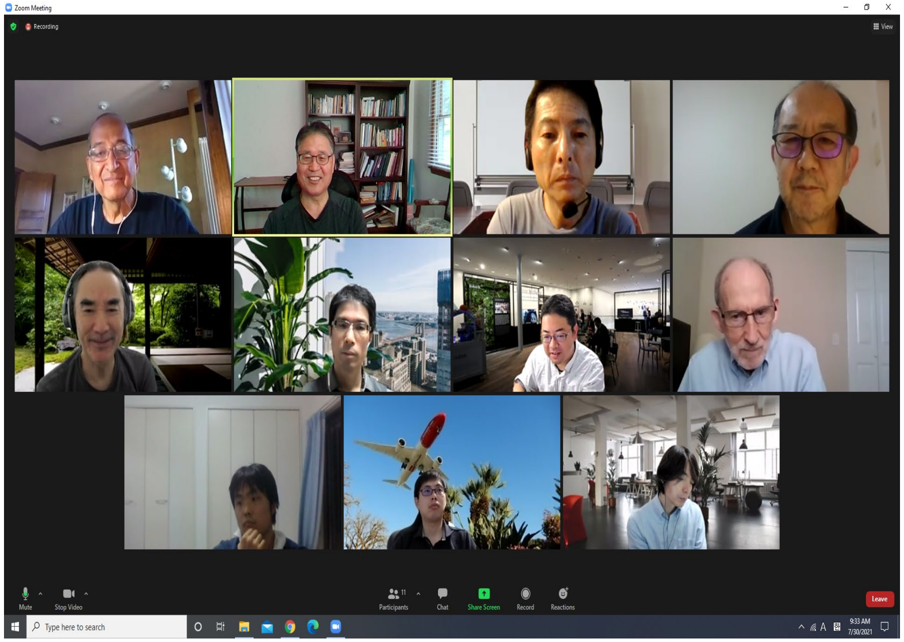
Communications

Regular Communications

- ➢Monthly Meeting via ZOOM
- ➢Created a mail list for all team members
- ➢Set up a file server

Visits

- ➢Pre-award meeting in Japan (June 2018)
- ➢Kyutech visit to CCNY (March 2019)
- ➢CCNY visit to Kyutech (September 2019)
- ~~➢Kyutech visit to CCNY (Early March 2020)~~ * Canceled due to COVID-19



Monthly Zoom progress meeting

Kyutech Campus (September 2019)

CCNY Campus (March 2019)

Pre-Award Meeting, Kyutech Campus (June 2018)

Accomplishments

- **Keynote**
  - T. Saadawi, “Secure Resilient Edge Cloud Designed Network,” INCoS 2019, Oita University, Oita, Japan
- **Journal** (10 papers, 4 of which are co-authored papers)
  - T. Saadawi , A. Kawaguhi, M. Lee, A. Mowshowitz, “Secure Resilient Edge Cloud Designed Network,” IEICE Transactions on Communications, (invited paper) Japan, Vol.E103-B, No.4, pp.292-301, April 2020.
  - K. Tsukamoto, H. Tamura, Y. Taenaka, D. Nobayashi, H. Yamamoto, T. Ikenaga, and M. Lee, “Geolocation-centric Information Platform for Resilient Spatio-temporal Contents Management,” IEICE Transactions on Communications, accepted (invited paper)
- **International Conference**
  - 48 papers, 20 of which are co-authored papers (*The number of JP side)
- **International Workshop WIND** (and Conference INCoS)
  - 18 papers (7 papers (2019), 6 papers (2020), 5 papers (2021))
  - JUNO2 session in WIND 2019, 2020, and 2021
- **Local Workshop in Japan**
  - 51 papers

Awards

- EIDWT 2019 Best Paper Award
  - N. V. Ha and M. Tsuru, “TCP with Network Coding Performance under Packet Reordering”
- DASC 2019 Best Paper Award
  - T. Morikawa and K. Kourai, “Low-cost and Fast Failure Recovery Using In-VM Containers in Clouds”
- WIND 2019 Best Paper Award
  - S. Shimokawa, T. Kanaoka, Y. Taenaka, K. Tsukamoto, M. Lee, “SDN-based Time-domain Error Correction for In-network Video QoE Estimation in Wireless Networks”
- ICACT-2020 Outstanding Paper Award
  - Nguyen Viet Ha, Le Van Hau, Masato Tsuru, “Dynamic ACK skipping in TCP with Network Coding for Power Line Communication Networks”

Testbed Progress

- ✓ Connection between CCNY (U.S.) and Kyutech (Japan) is up and running
- ✓ Initial International experiments are underway
- ✓ CCNY COSMOS (NSF) node is almost active
- ✓ COSM-IC (NSF) fiber is in the process of being installed to achieve Japan connection

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CCNY - Kyutech testbed

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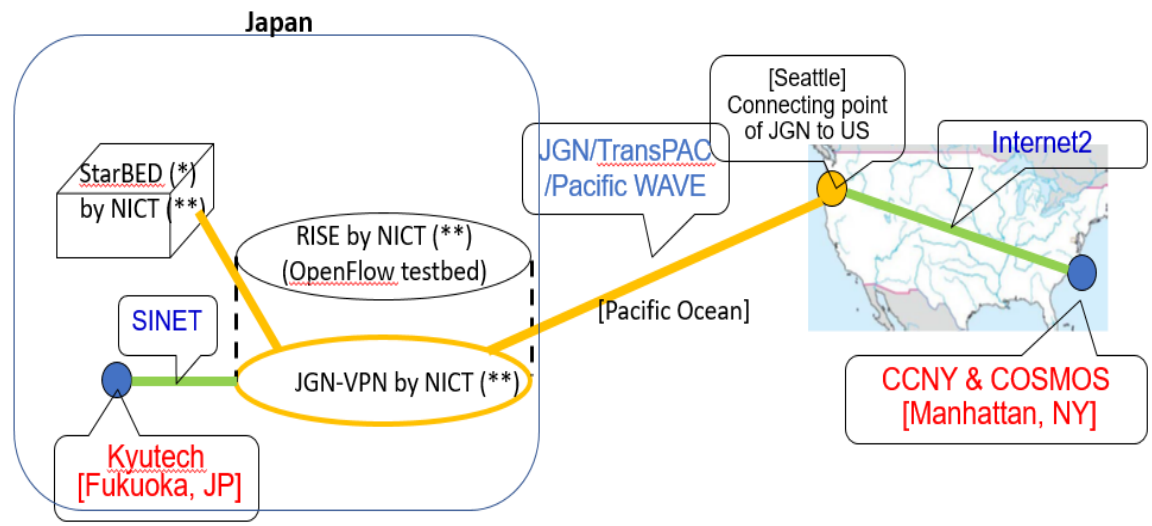
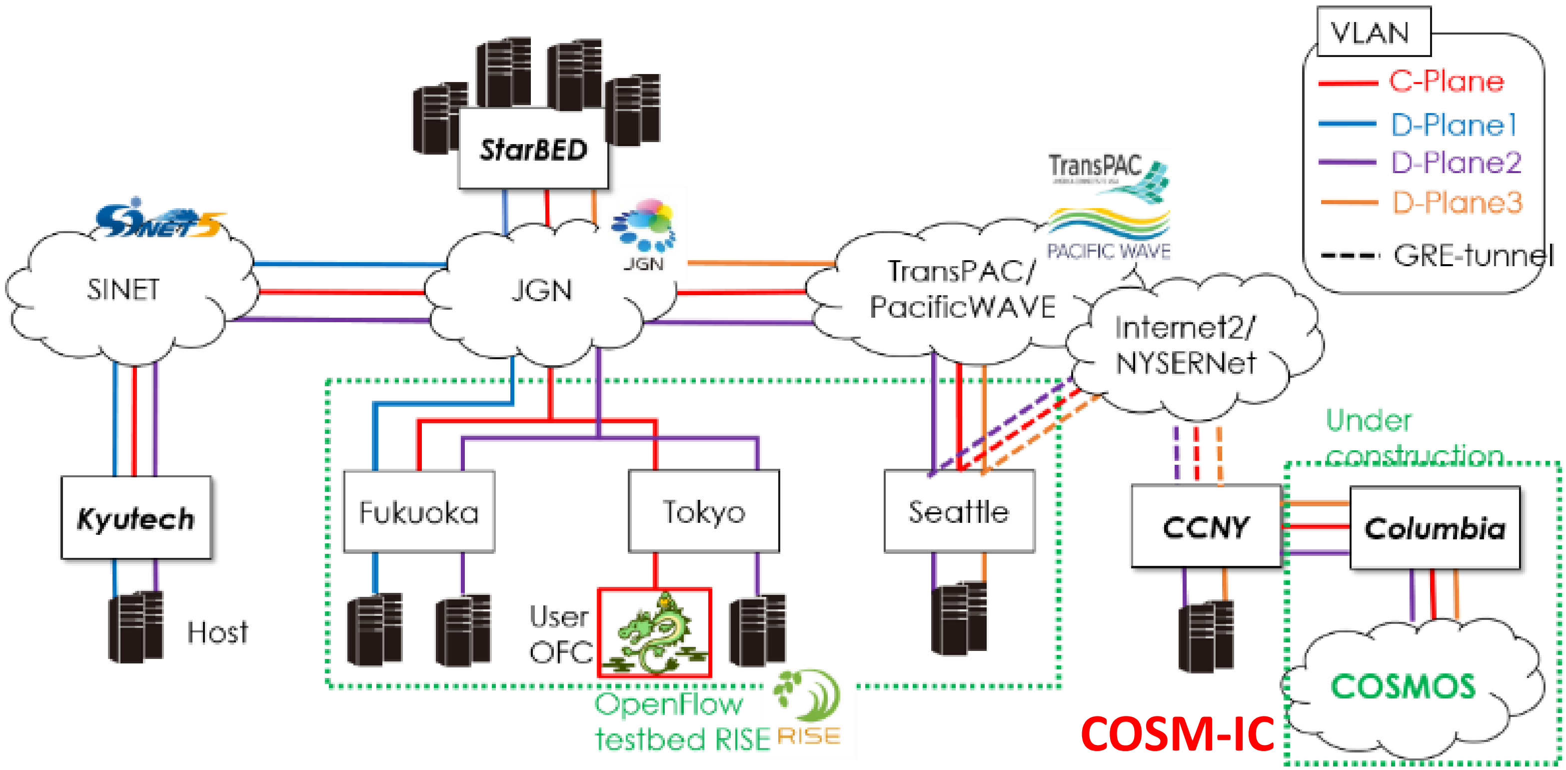
- ✓**Integrated Large-Scale Real and Emulation Experimental Testbed**: **CCNY**, **Kyutech**, **StarBED** (a large-scale emulation/simulation testbed), and **RISE** (OpenFlow testbed) for a global edge-cloud networking testbed across US and JP.
    - ✓**GRE-tunnel** is used to extend VLANs between CCNY and JGN-Seattle.

CCNY-Kyutech, COSMOS Interconnection



(*) StarBED: a large-scale emulation testbed for networking, network applications, information security, and cyber physical systems.

(**) NICT: National Institute of Information and Communications Technology, Japan



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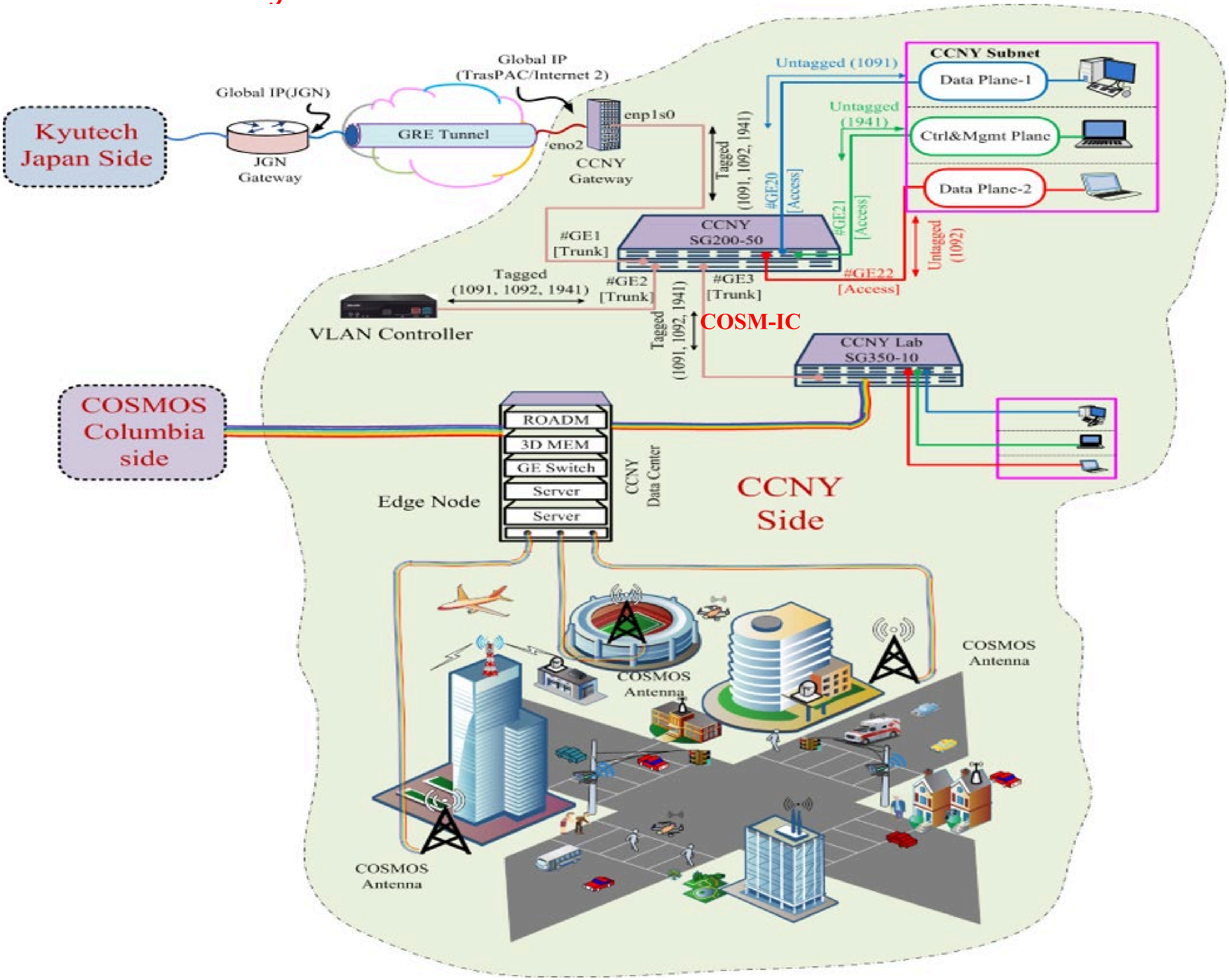
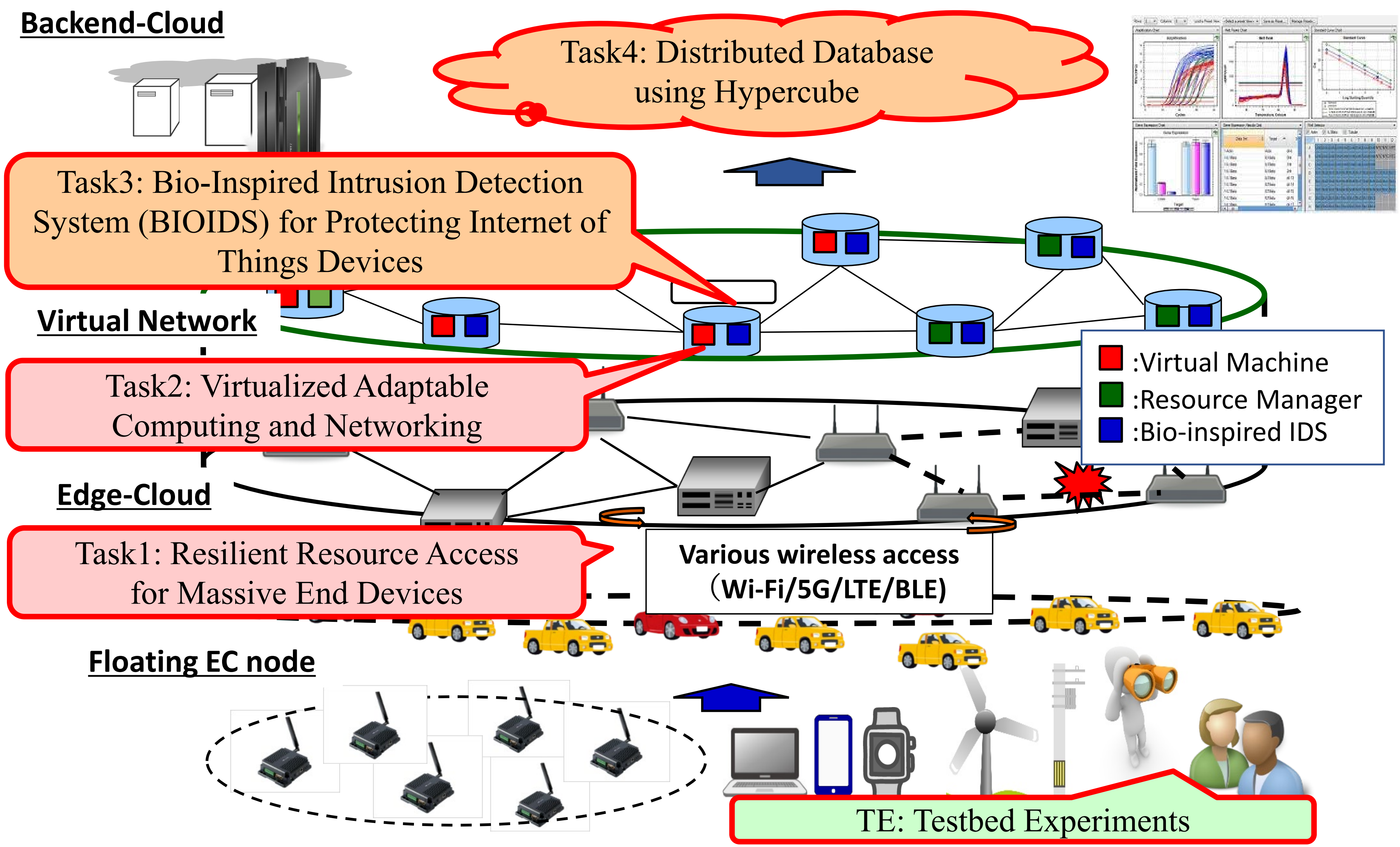
Current CCNY-Kyutech Testbed



Testbed Future Directions and Real-time International Experimentations

1) Working on the fiber installation between COSMOS node (NAC Bldg) and the wireless lab (Eng Bldg)
2) Working on the fiber installation between the wireless lab (COSMOS access) and the cybersecurity Lab (Japan connection)
3) Refining and further testing CCNY-Kyutech connection (bit rate, delay, etc.)
4) Realtime International Experimentations;
    a. Secure VM Introspection
    b. Blockchain cooperative intrusion detection systems
    c. Resource Allocation in MEC
    d. Virtual work space by Edge-cloud for a US business person visiting to JP
    e. Paper on international experimentation planned (deadline end of August)

Overview of RECN



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Tasks

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- **TASK 1: RESILIENT RESOURCE ACCESS FOR MASSIVE END DEVICES**

  Task Members: **Myung Lee** (CCNY), **Kazuya Tsukamoto**, Takeshi Ikenaga, Daiki Nobayashi (Kyutech)

- **TASK 2: VIRTUALIZED ADAPTABLE COMPUTING AND NETWORKING**

  Task Members: **Masato Tsuru**; Kenichi Kourai; Kenji Kawahara; Masahiro Shibata (Kyutech), **Akira Kawaguchi**; Abbe Mowshowitz (CCNY)

- **TASK 3: BIO-INSPIRED INTRUSION DETECTION SYSTEM (BIOIDS) FOR PROTECTING INTERNET OF THINGS DEVICES**

  Task Members: **Tarek Saadawi** (CCNY), **Kenichi Kourai** (Kyutech)

- **TASK 4: DISTRIBUTED DATABASE USING HYPERCUBE**

  Task Members: **Abbe Mowshowitz**, Akira Kawaguchi (CCNY); Masato Tsuru, **Shibata Masahiro** (Kyutech)

- **TESTBED EXPERIMENTS**

  Task Members: **Masato Tsuru (Kuytech), Myung Lee (CCNY)** and all team members

  Test scenarios:
  1) Safety by facial recognition.
  2) Managing a distributed electric power grid based on designed hypercube network
  3) Examples of previous tasks
  4) Blockchain for cooperative IDS's

T1: Resilient Resource Access for Massive End Devices

- ✓ To provide resiliency, the distributed EC system supports:
- ✓ In normal situation:
  1. Flow-based resilient communication between end-devices and an EC node via interface diversity
  => SDN allocates the appropriate resources based on the estimated QoE of each flow
  2. Optimal resource allocation among end-device, EC, and BC to meet a diverse QoE requirements such as **latency and blocking rate.**

=> propose an algorithm for the RM to optimally allocate computing (VM) and bandwidth resources.

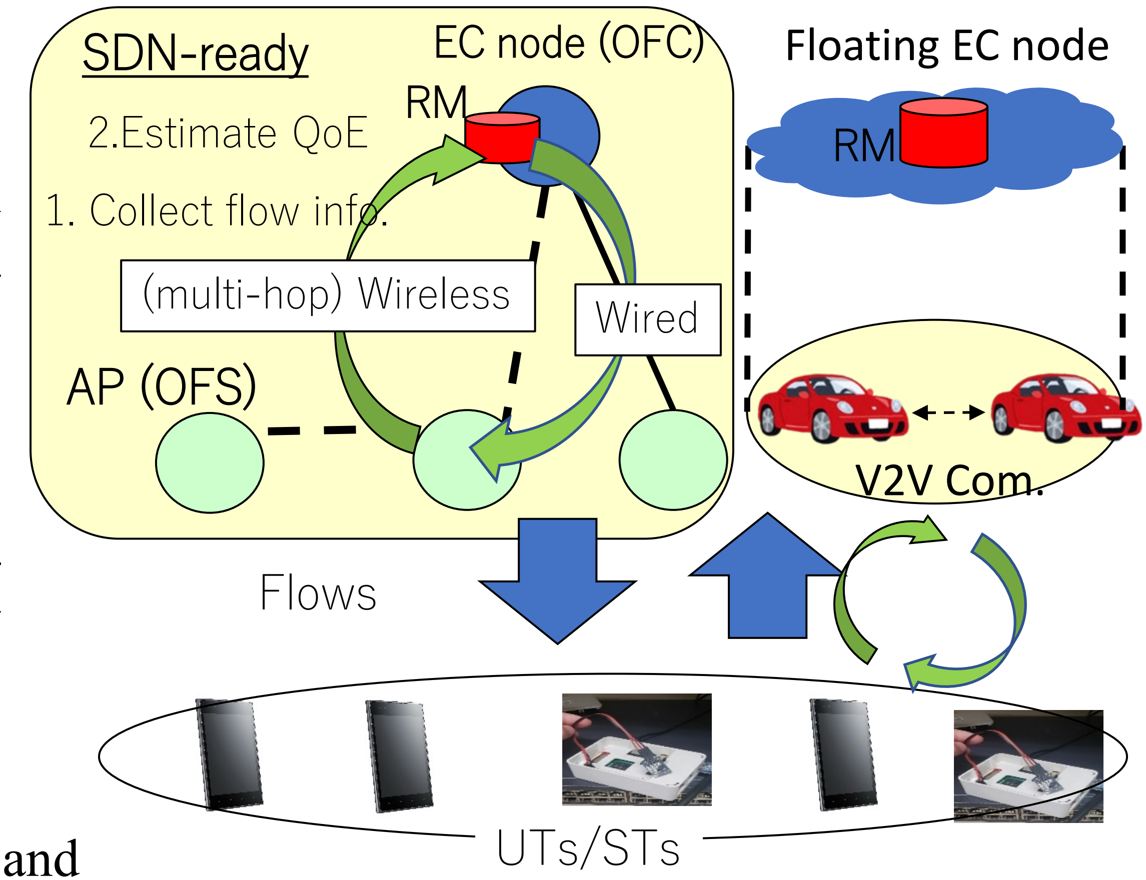

Fig. Concept of End-device networking

- ✓ In resilient situation:
  3. coverage maintenance/extension by introducing spatio-temporal floating EC nodes

Task Members:
Myung Lee (CCNY); Kazuya Tsukamoto, Takeshi Ikenaga, Daiki Nobayashi (Kyutech)

Task1.1: Spatio-temporal Floating EC function over vehicular nodes

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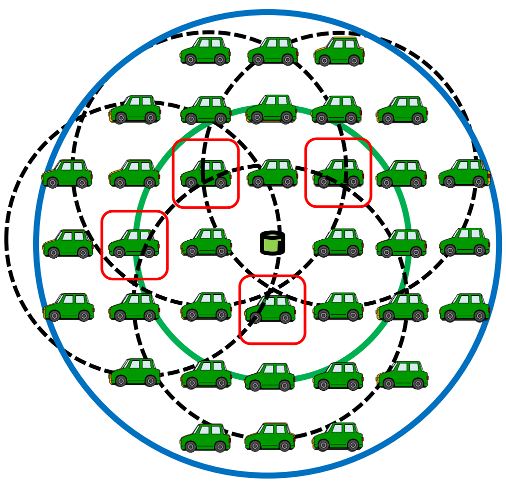
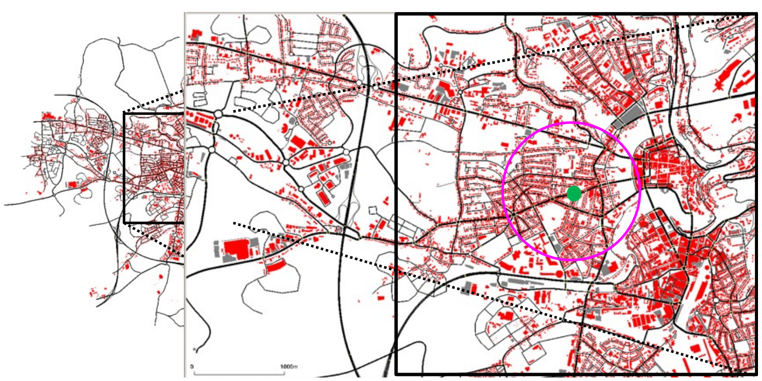
- To achieve floating EC function for providing resiliency of EC node, we propose the data retention system by using vehicular nodes.
  - A vehicular network near the EC node diffuses and retains data (or functions) of the EC node and the Resource Manager (RM).
  - We propose appropriate data transmission scheme that can efficiently use wireless resources while maintaining service coverage.
  - As a result, Floating EC provided by the data retention system can provide EC functions to the user when the fixed EC node is down.

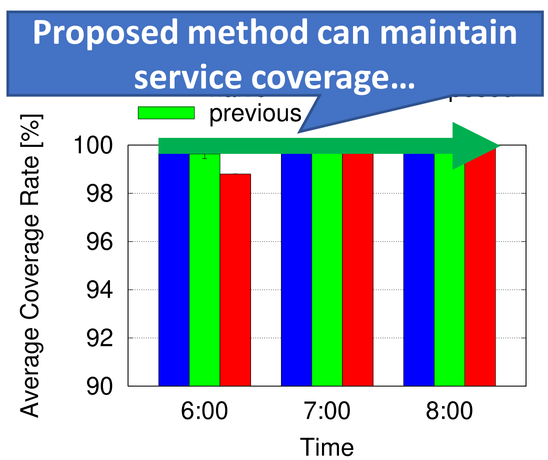


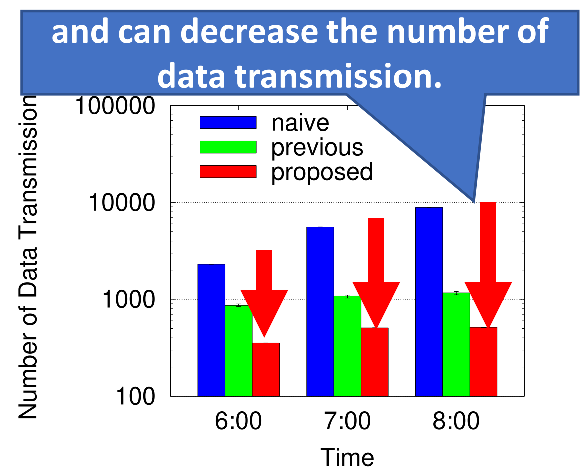
An Overview of Data Retention System



Luxembourg's traffic model

- Experiment
  1. We evaluate our proposed scheme using **the network simulator Veins (OMNeT++ and SUMO) and realistic traffic model of Luxembourg (LuST)**.
  2. To evaluate the feasibility of Floating EC, we conducted a demonstration experiment using **Smithsonian, which is a multi-agent emulation and simulation environment by NICT**.
- Results



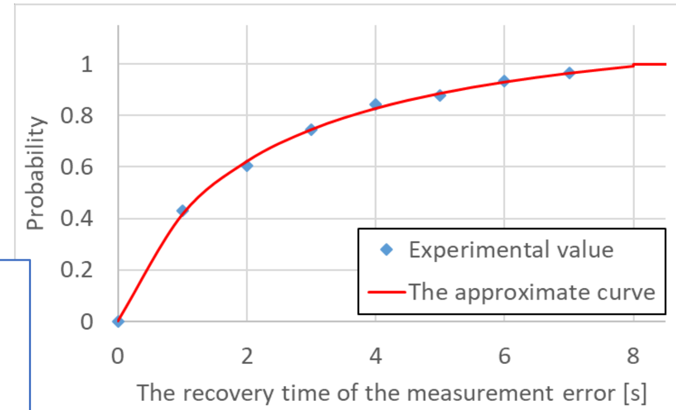


Simulation Results using Luxembourg's traffic model

*The number of vehicles peaked at 8:00 AM.

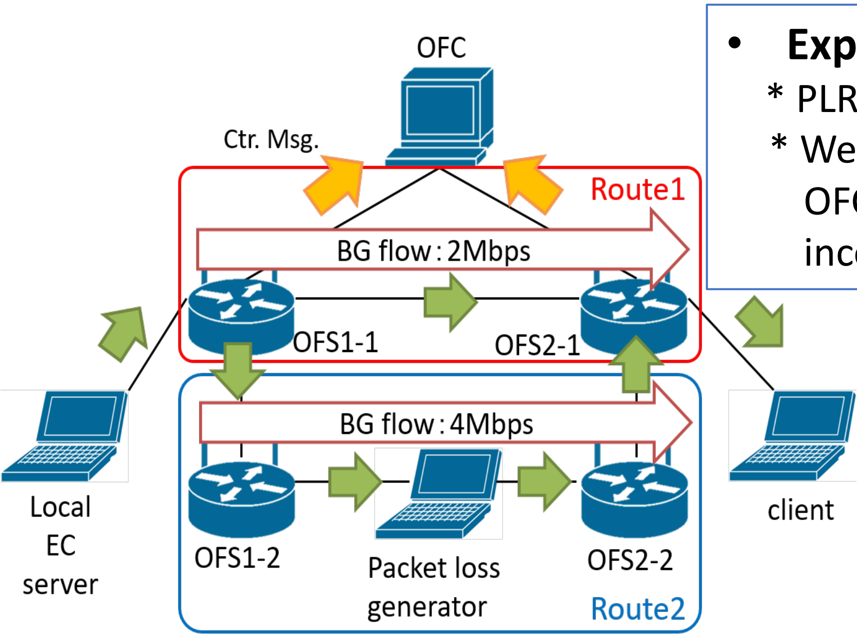
T1.2: Flow-based resilient communication

- To achieve resilient communication via flow-based control, we propose the following three functions.
  1. <u>An Identification method for new arrival flow using OpenFlow control messages</u>
     - RTP flow can be identified correctly based on ML by using first 15 consecutive **pkt_ins**
  2. <u>SDN-based in-network two-staged video QoE estimation method</u>
     - **1st stage: PortStats** is used for rough QoE estimation
     - **2nd stage: FlowStats** is used for precise QoE estimation for ongoing flow with **measurement error correction**
  3. <u>Route selection method by exploiting functions of 1. and 2.</u>

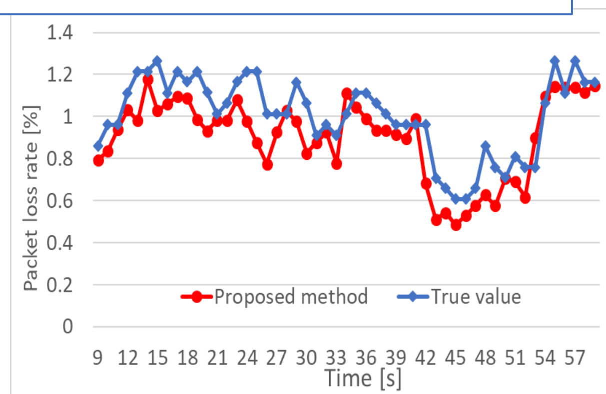


CDF of the meas. err. recovery time

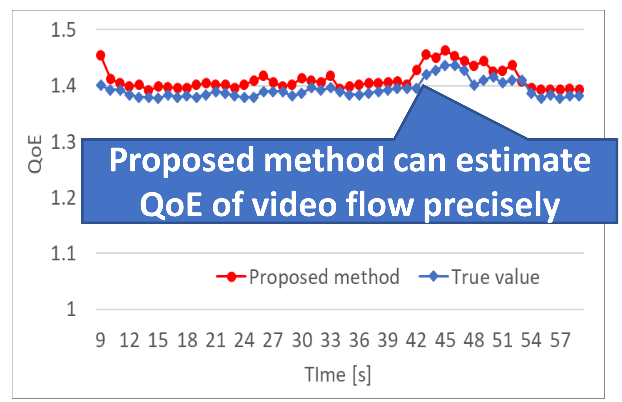
- **Experiments**
  * PLR is set to 1% (severe condition)
  * We measure in-network (at the OFC) estimated QoE of the incoming RTP flow (G.1071)



Network topology for experiment



Time series in estimated PLR



Time series in estimated QoE

Proposed method can select a better route with higher QoE for video flow under lossy env.
-> **Flow-based resilient communication can be achieved!**

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T1.3: Joint Multi-resource Optimal Allocation Framework

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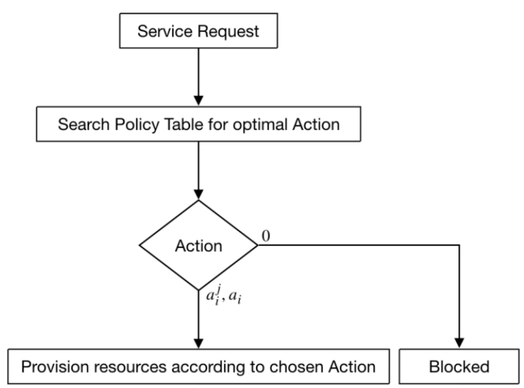
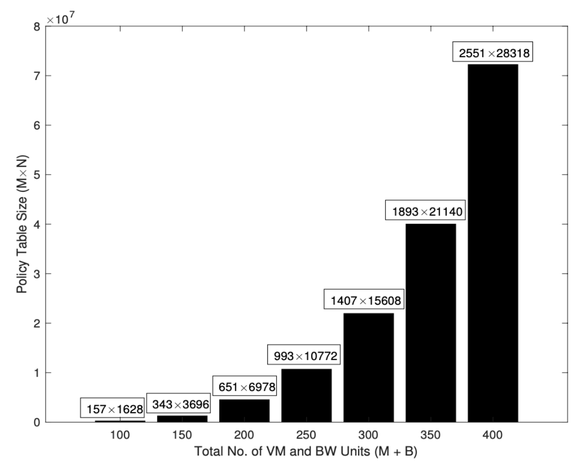
- To scale Semi-Decision Markov Process(SMDP) multi-resource allocation framework for real-world scenarios in EC-based systems we propose to:
  1. **Structure the optimal resource allocation policy table** in a simple two-dimensional matrix
     - Columns represent the occurrences of the states of the system
     - Rows represent probabilities of actions taken by the system in their corresponding states (columns)
  2. **Index-based search technique over structured policy table**
     - The indices of the states, actions and max occurrences of the states are stored as $1 \times N$ vectors
     - System has information about the current state (column), therefore, rest of the columns are eliminated during the search
     - RM decides actions depending on the probabilities

	x_1^2				x_2^1			
	0	1	2	3	0	1	2	3
a_1^1	0	0.32	0.44	0.40	0	0.45	0.55	0.44
a_1^2	0.53	0.20	0.16	0.20	0.45	0.30	0.30	0.18
a_2^1	0.47	0.48	0.12	0.05	0.55	0.20	0	0
a_i^j	0	0	0	0	0	0	0	0
a_1	0	0	0.13	0.20	0	0.03	0.08	0.12
a_2	0	0	0.15	0.10	0	0	0.02	0.01
a_i	0	0	0	0	0	0	0	0
0	0	0	0	0.05	0	0.02	0.05	0.25

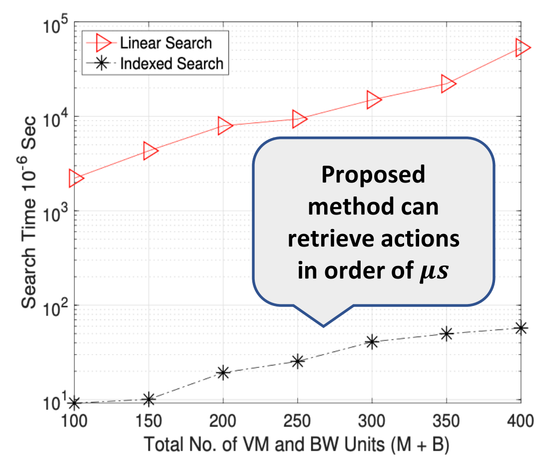
Policy Table for Service Requests



Search-Flow for resource provisioning by RM



Exponential growth in PT: ~72 Million



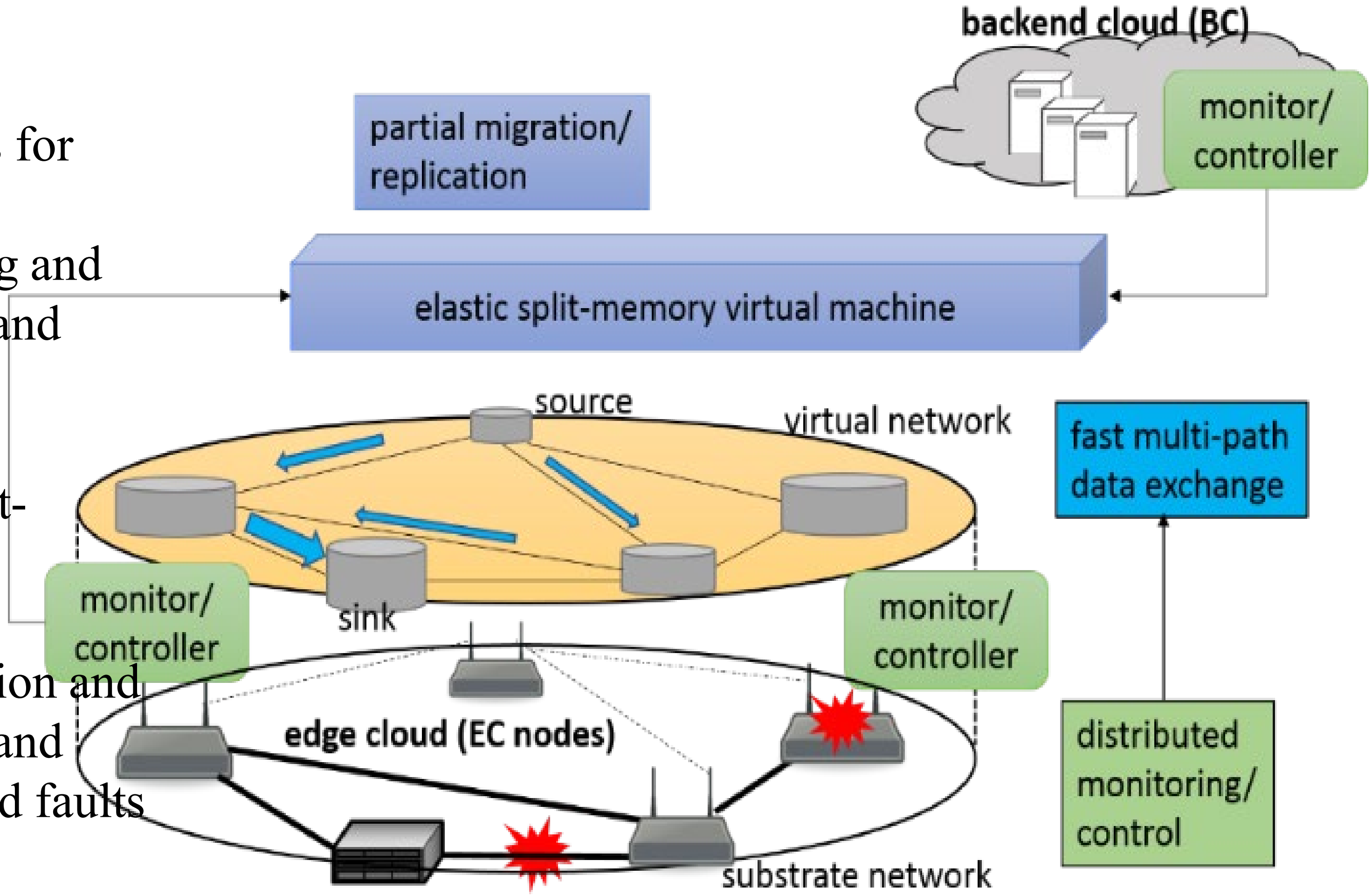
Search time comparison

Index-based search helps the resource manager to retrieve optimal actions in the order of microseconds for real-time applications in EC-based systems

Task 2: Virtualized Adaptable Computing and Networking

✓Goal: Platform for geographically distributed information sharing and processing with resiliency across edge (EC) and backend clouds (BC)
✓Issues: Resources (computation, storage, communication) => heterogeneous, distributed, and limited; Demands on the resources => diverse and variable in time and space
✓Subtasks (T2-1,2,3,4):

(1) Fast multi-path data exchange among EC/BCs for migration and replication
(2) Distributed monitoring and control of links to detect and cope with degradation
(3) Partial migration and replication for elastic split-memory VMs in EC/BCs
(4) Distributed introspection and control of VMs to detect and recover from intrusion and faults



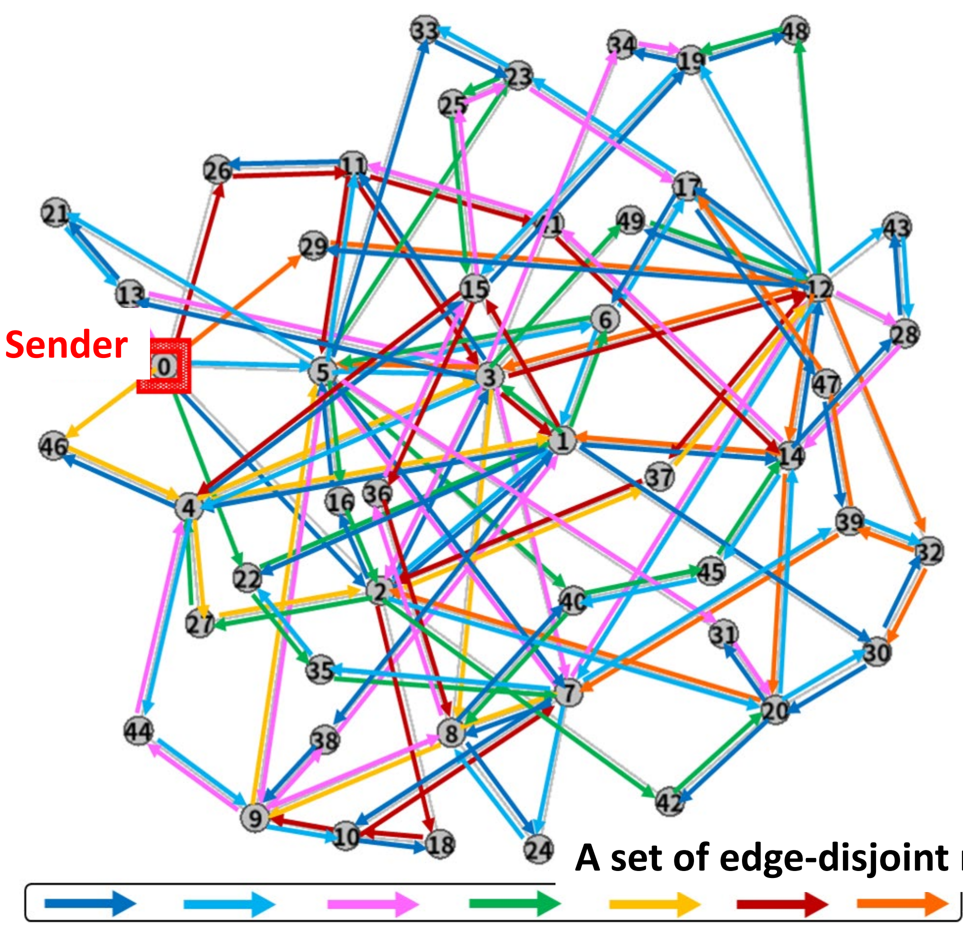
Task Members: Akira Kawaguchi, Abbe Mowshowitz (CCNY); Masato Tsuru, Kenichi Kourai, Kenji Kawahara, Masahiro Shibata (Kyutech)

T2.1: Fast multi-path data exchange

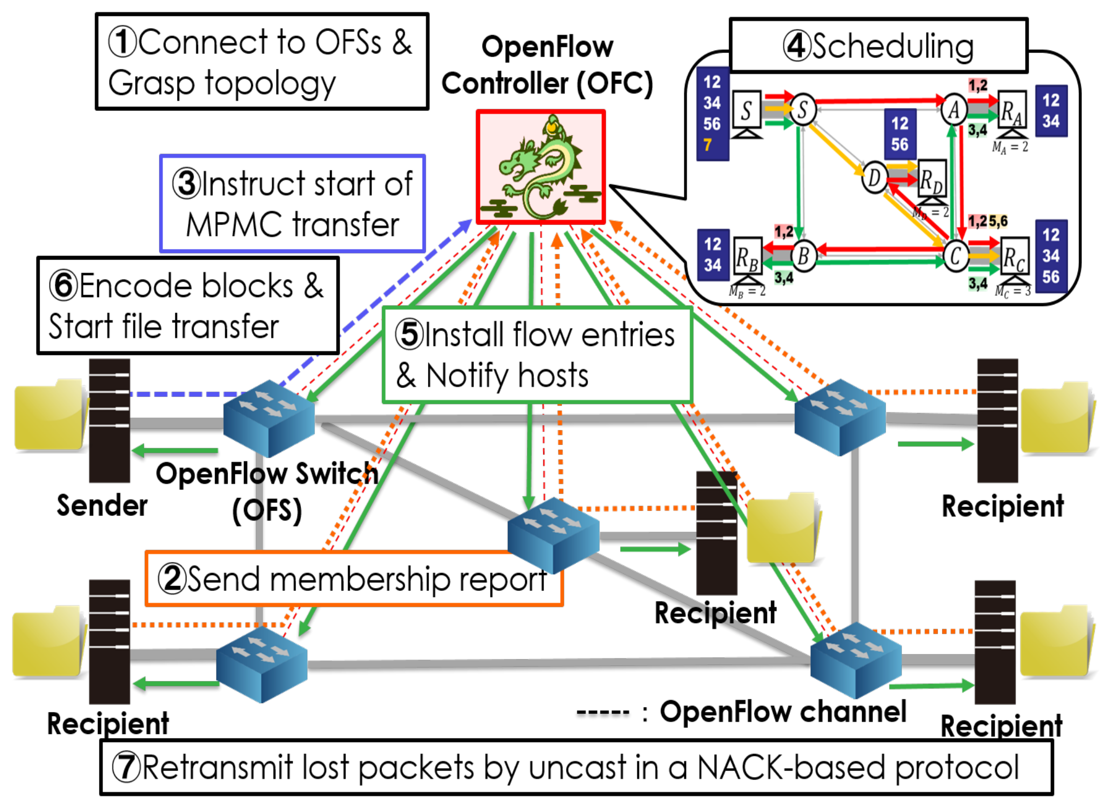
✓**Coded-MPMC:** One-to-many file transfer by (1) Multipath, multicast, and multiphase delivery of a file from the **sender** to each of many **recipients** on its **max-flow paths** + (2) Block coding (e.g. RS) at the sender + (3) Heuristics on block allocations

=> **Minimize the file retrieval completion time of each recipient.**

- ✓Simulation: Validation on a variety of large-scale network topologies.
- ✓OpenFlow (OF)-based prototype implementation: Evaluation on Mininet, InLab-OF network, and the US-JP testbed.



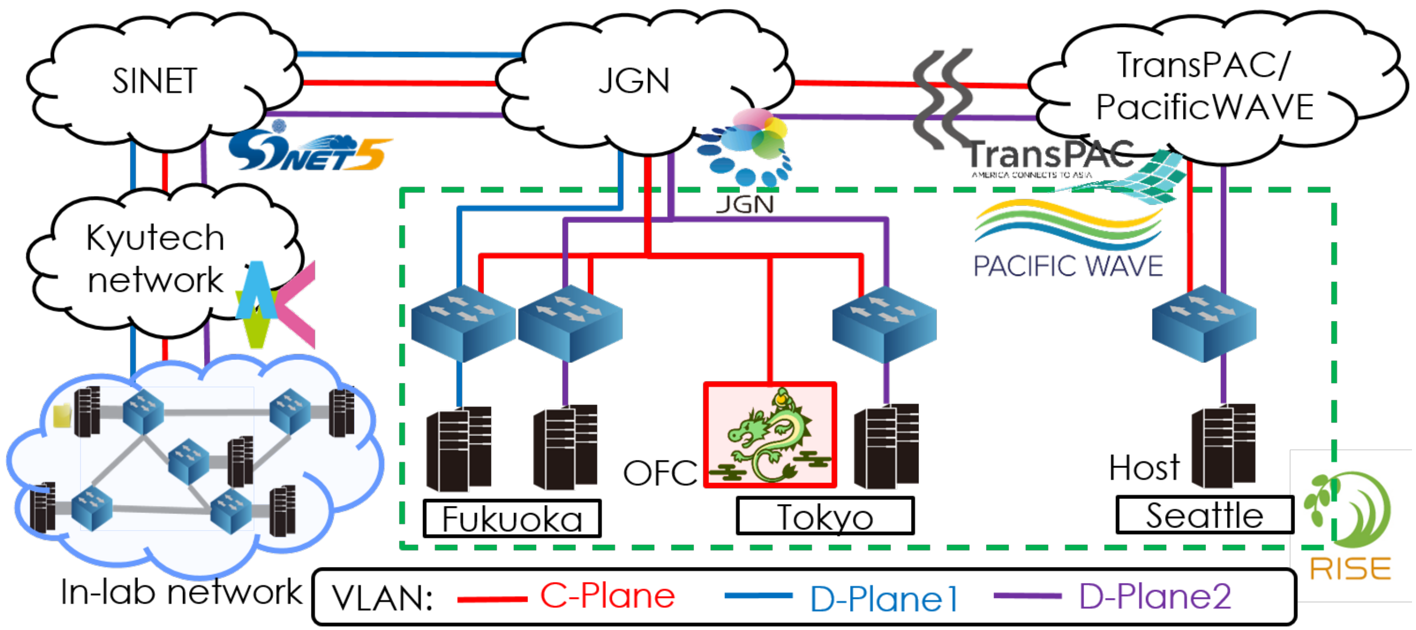
A set of edge-disjoint multicast trees

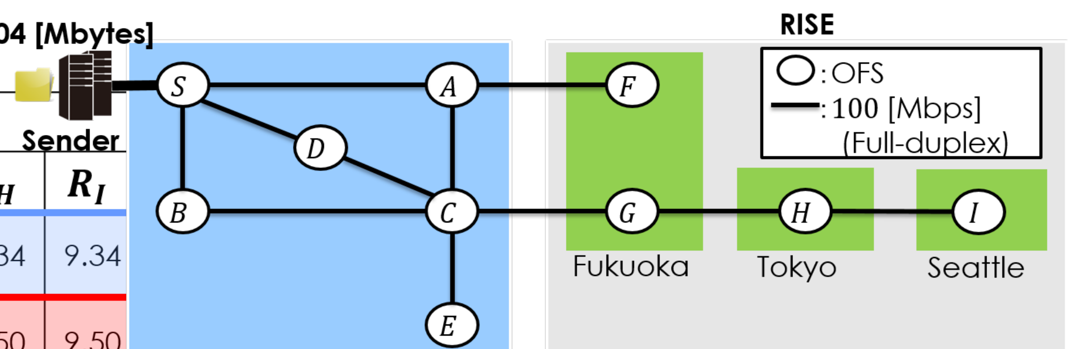


T2.1: Fast multi-path data exchange (2)

✓**Experiments on the US-JP testbed** for **Coded-MPMC:**

- ✓Connecting InLab-OF network and **RISE** (a global OF testbed operated by NICT).
- ✓A Ryu-based OF controller is set up at Tokyo to manage the one-to-many file transfer from a sender to 9 recipients (one is at Seattle).



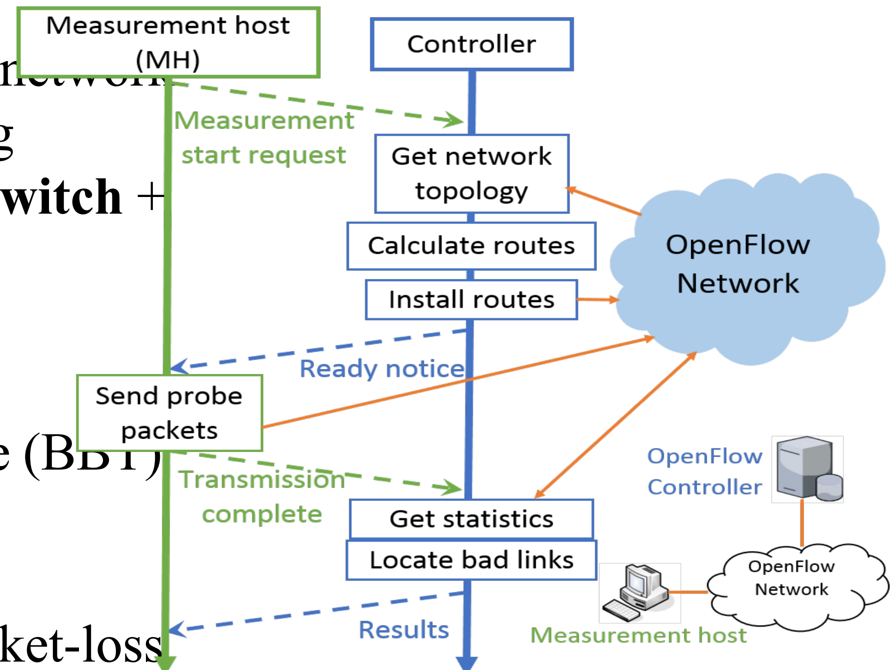


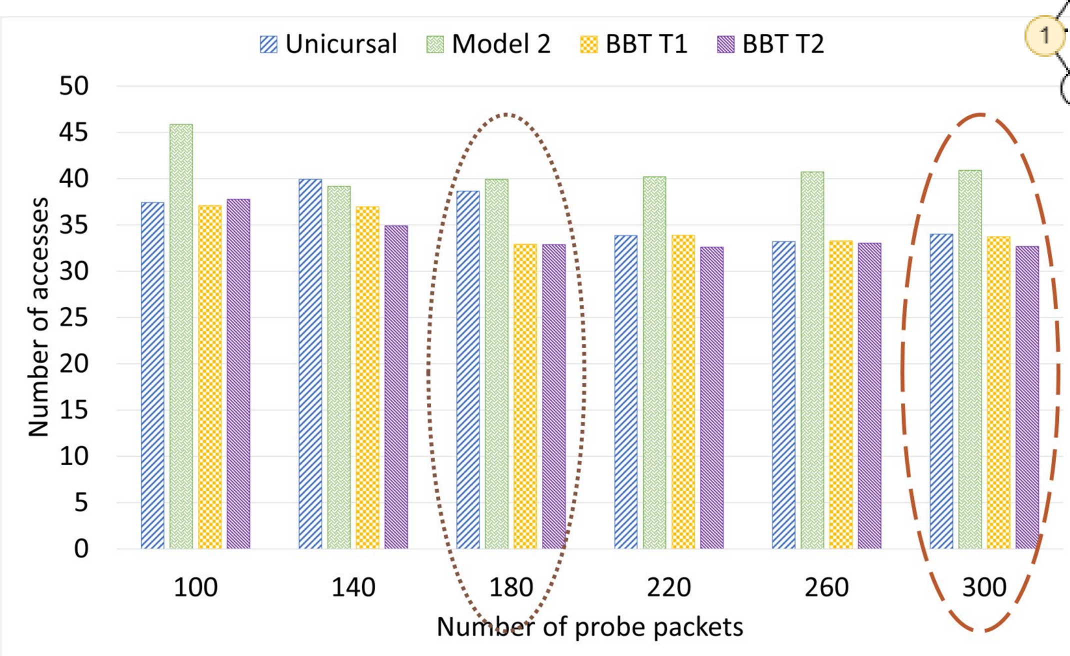
Location	Our in-lab network					RISE			
Recipient	R_A	R_B	R_C	R_D	R_E	R_F	R_G	R_H	R_I
Theoretical RCT [s]	4.67	4.67	3.11	4.67	9.34	9.34	9.34	9.34	9.34
Experimental RCT [s] (**Without** Packet-loss)	4.71	4.71	3.14	4.71	9.50	9.50	9.50	9.50	9.50
Experimental RCT [s] (**With** Packet-loss)	4.71	4.71	3.14	4.71	9.50	10.21	10.21	10.22	10.32

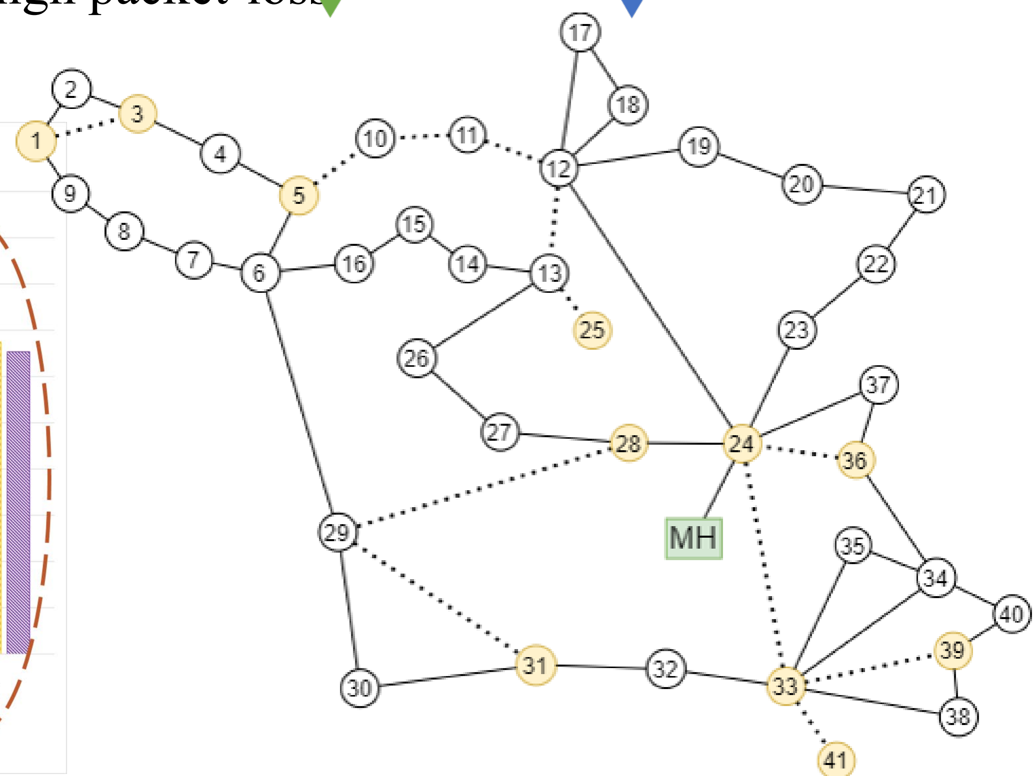
T2.2: Distributed monitoring of network links

✓**Network-Assisted Monitoring Framework**:
Detection/location of bad links on OpenFlow (OF) network by (1) Packet proving from one or more **MHs** along **multicast routes** + (2) Packet monitoring at each **Switch** + (3) Selective collection of (2) by **Controller**.
=> **Minimizing the overhead incurred by the measurement to data & control planes**.

- ✓By Euler circle-based design of multicast route (BBT) and Network tomographic access ordering for monitored results collection.
- ✓Simulation & Mininet Emulation: for high packet-loss and high packet-delay-variance.

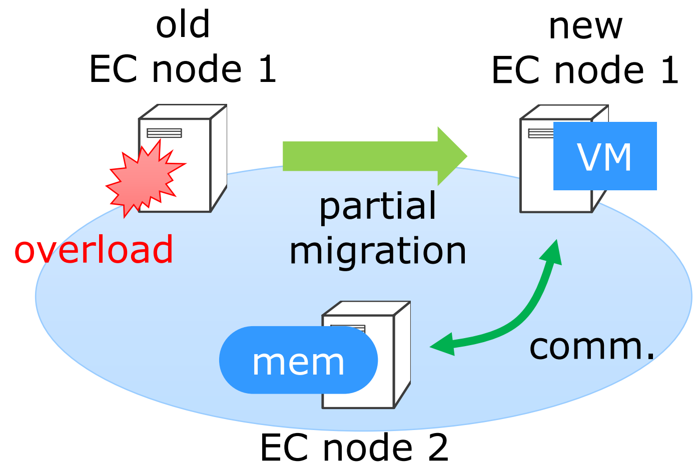




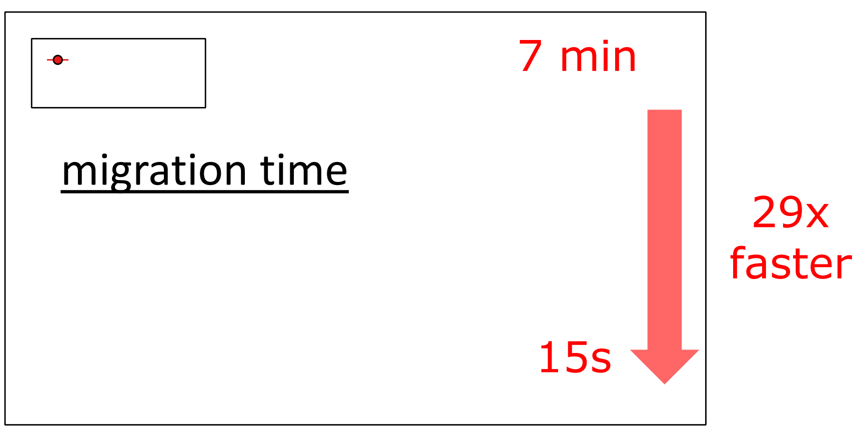


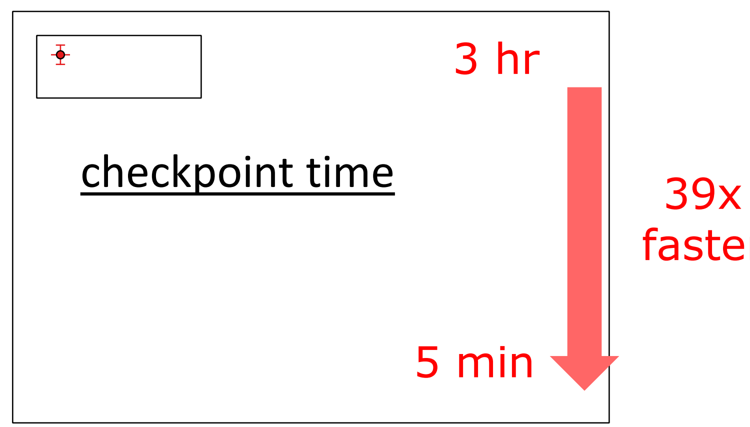
T2.3:Elastic split-memory VMs in EC nodes and BC

- Partial migration of split-memory VMs
  - A split-memory VM runs across EC nodes and BC to process big data
  - Efficiently move only part of a VM from overloaded EC nodes to others



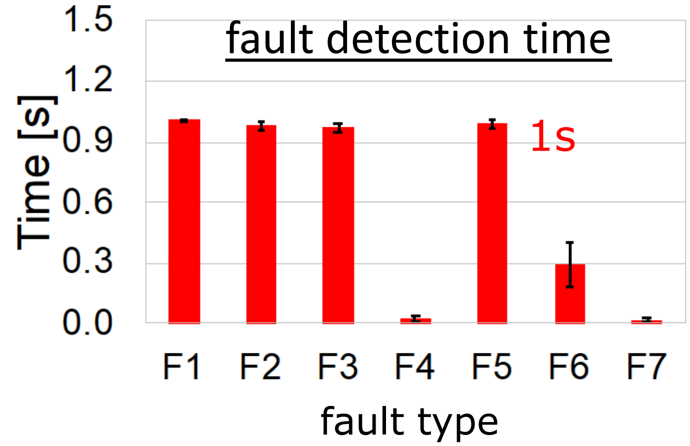
- Optimization of network communication for split-memory VMs
  - Avoid transferring the data of unused memory in a VM (left figure)
  - Transparently identify memory regions that are not used by the system in a VM
- Efficient checkpoint/restore for split-memory VMs
  - Independently save a VM state at each node in parallel (right figure)
  - Quickly restore the saved VM state upon an EC node failure



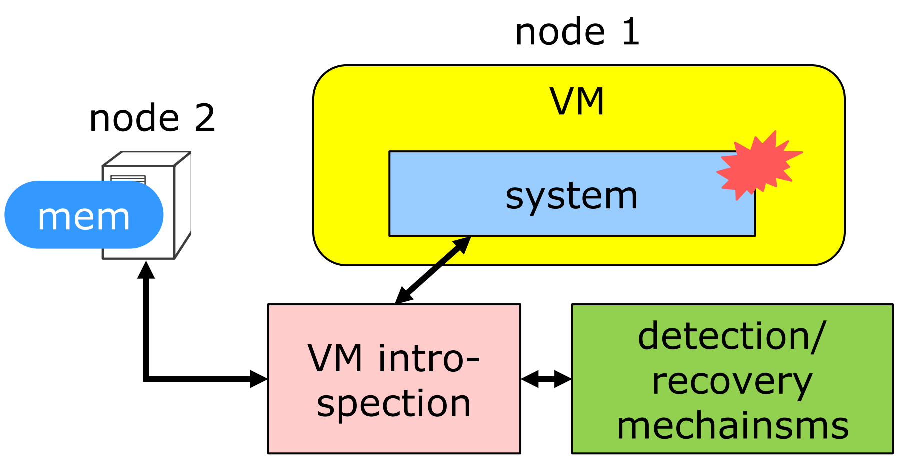


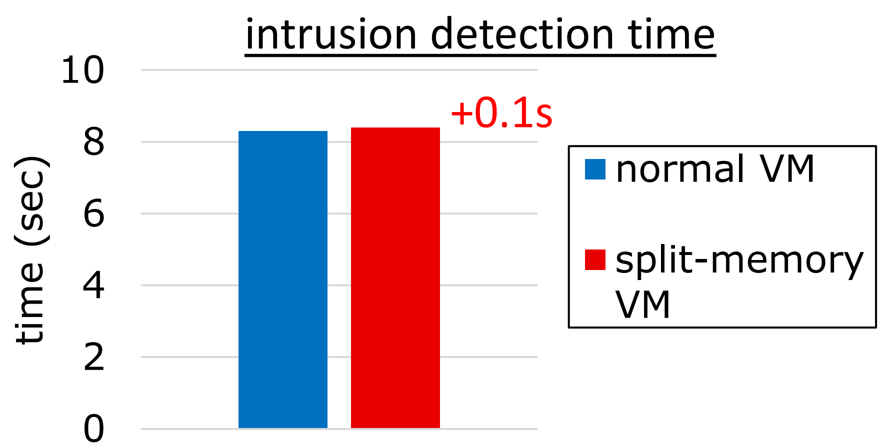
T2.4:Distributed introspection and control for resiliency of split-memory VMs

- Fault detection of the system inside a VM
  - Safely monitor OS data in the memory of a VM using VM introspection
  - Obtain detailed information without being affected by system faults
  - E.g., CPU/memory utilization, process info, etc.



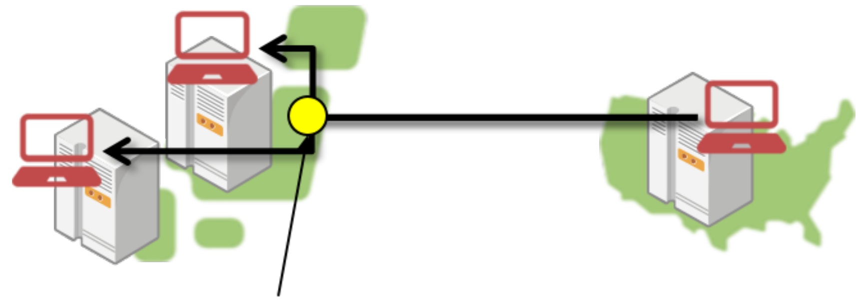
- Fault recovery of the system inside a VM
  - Rewrite OS data in the memory of a VM using extended VM introspection
  - E.g., terminating anomaly processes by emulating to send KILL signals
- Intrusion detection for split-memory VMs
  - Transparently access the distributed memory of a VM across multiple nodes
  - Monitor OS data, virtual disks, and virtual networks in a VM

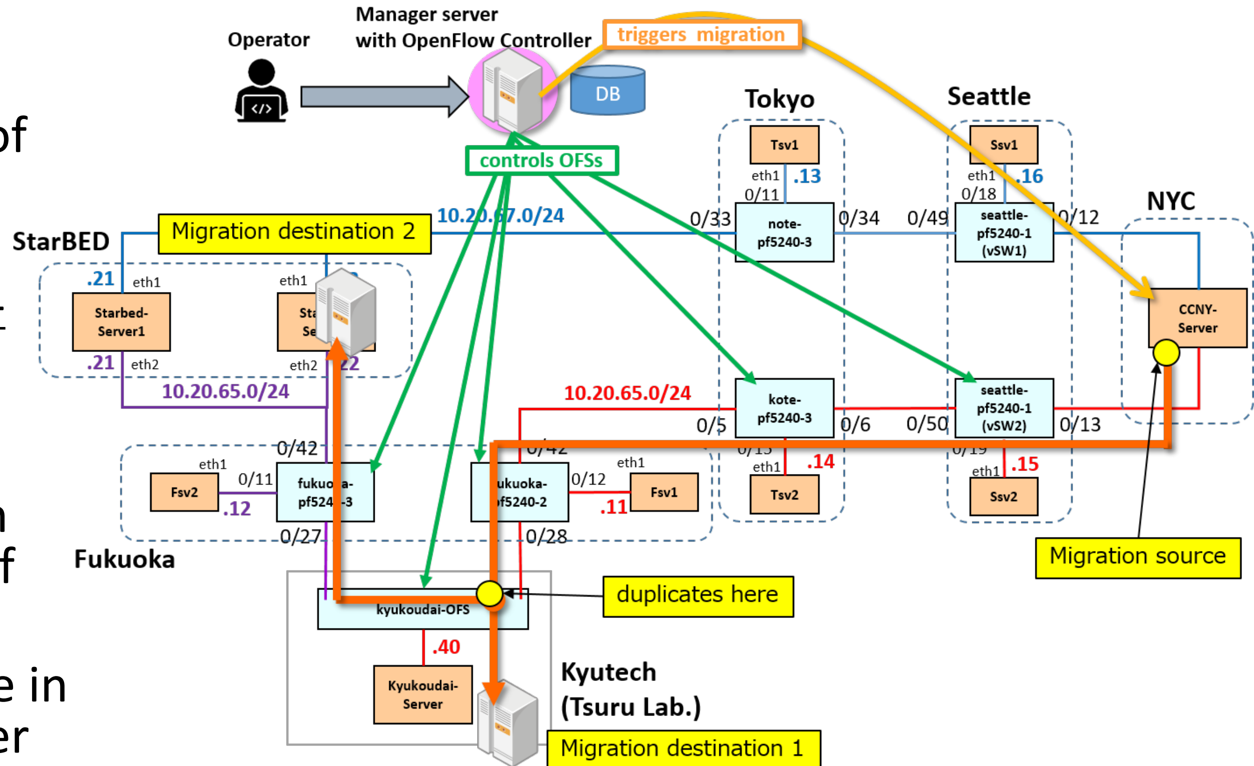




Testbed Experiment (Task2)

- **Scenario:** Virtual work space by Edge-cloud for a US business person visiting to JP
  - Migrate her VM running in CCNY to multiple sites (StarBED and Kyutech) in JP for delay-sensitive work.
  - Implement the multicast-migration for an instant use of the VM regardless of her location.
  - Compare it with the cascade-migration.
- **Demo**
  - Use a 3D CG tool on VM from her PC located at a campus of Kyutech.
  - Compare the user-experience in terms of VM location: another campus in kyutech (near edge), StarBED (far edge), and CCNY (original site).





Task 3 **Secure VM Introspection**

International Realtime Testbed Experiment

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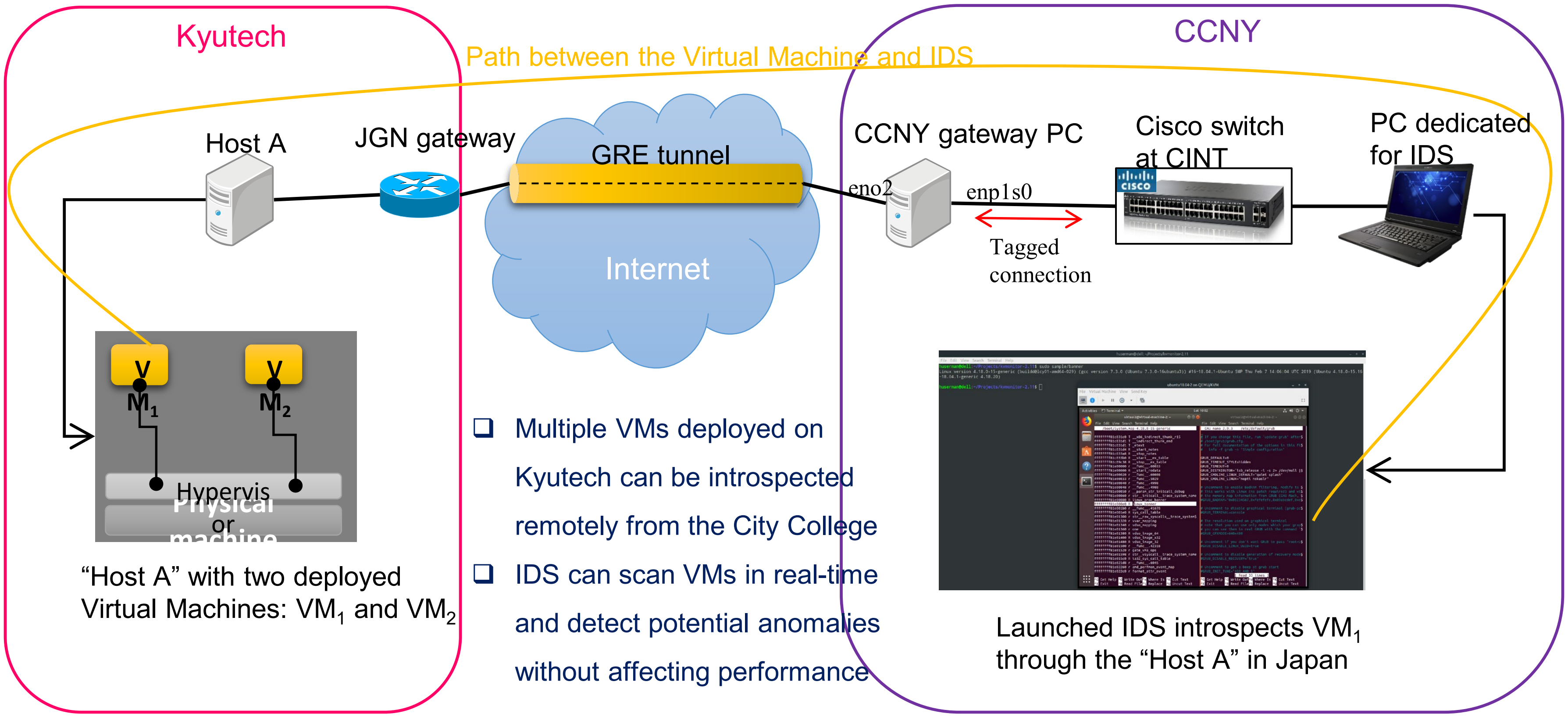
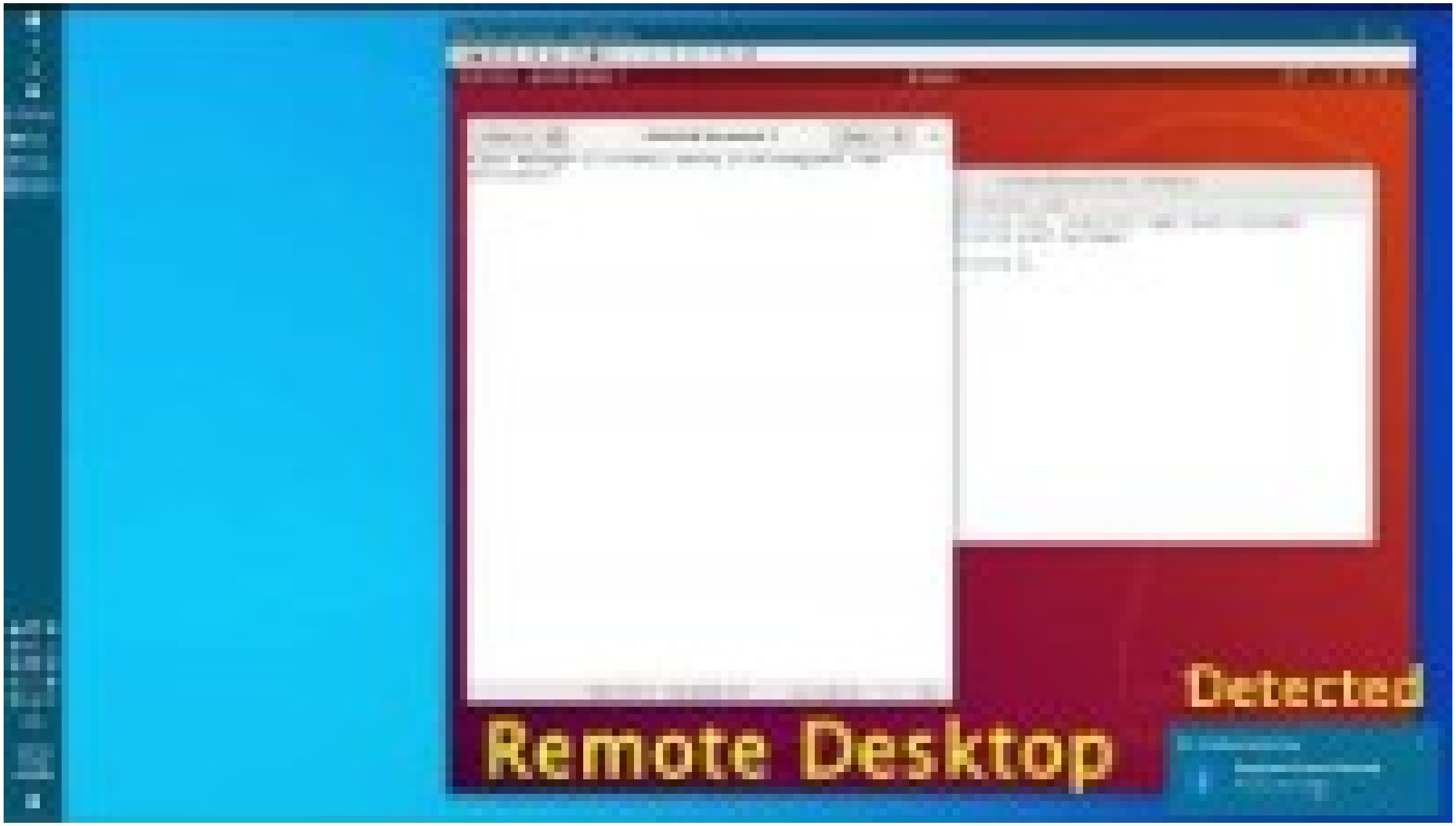
Scenario: **A Japanese business person makes an overseas trip to US; Access his/her VM running in Japan from US, Use remote desktop (VNC) in his/her laptop PC, Monitor attacks against the VM by running BioIDS in his/her laptop PC**



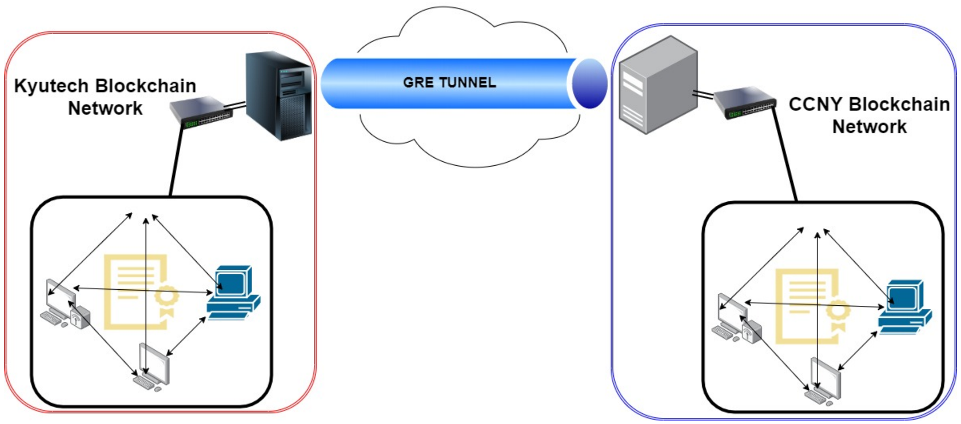
- Multiple VMs deployed on Kyutech can be introspected remotely from the City College
- IDS can scan VMs in real-time and detect potential anomalies without affecting performance

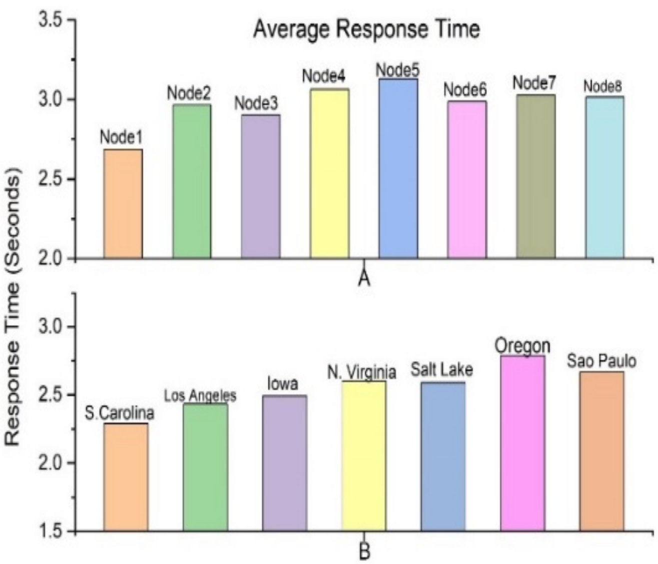
Task Members: Tarek Saadawi (CCNY); Kenichi Kourai (Kyutech)



- DEMO
- Applied for joint patent (CCNY and Kutech)

2) Interdomain Blockchain Co-IPS Experiment





- **Ran an Interdomain real-time experiment for co-operative intrusion detection system (Co-IDS)**

- **Initial results show the average response time of each node (time for other nodes receives the attack signature) to lie between 2.5 to 3.0 seconds**

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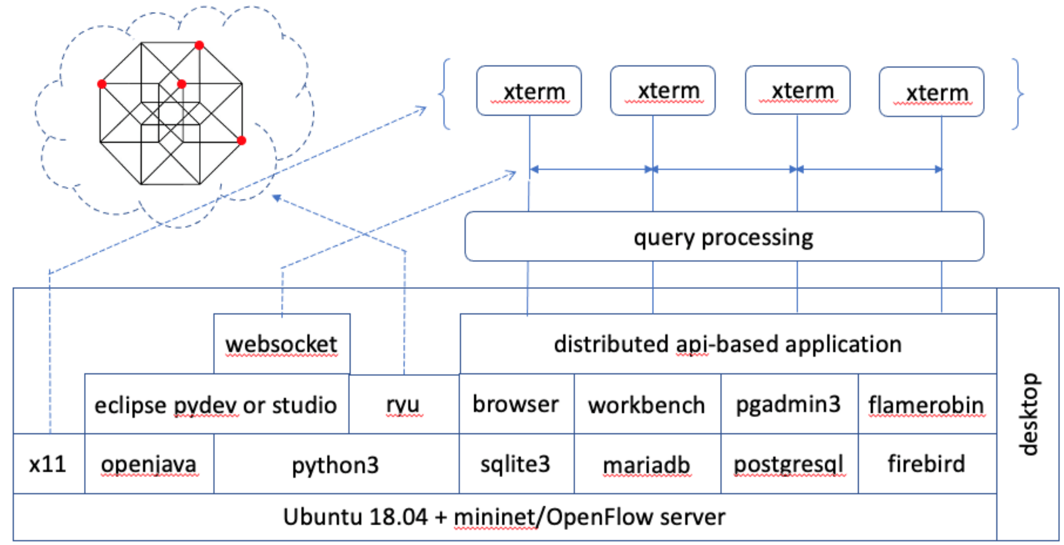
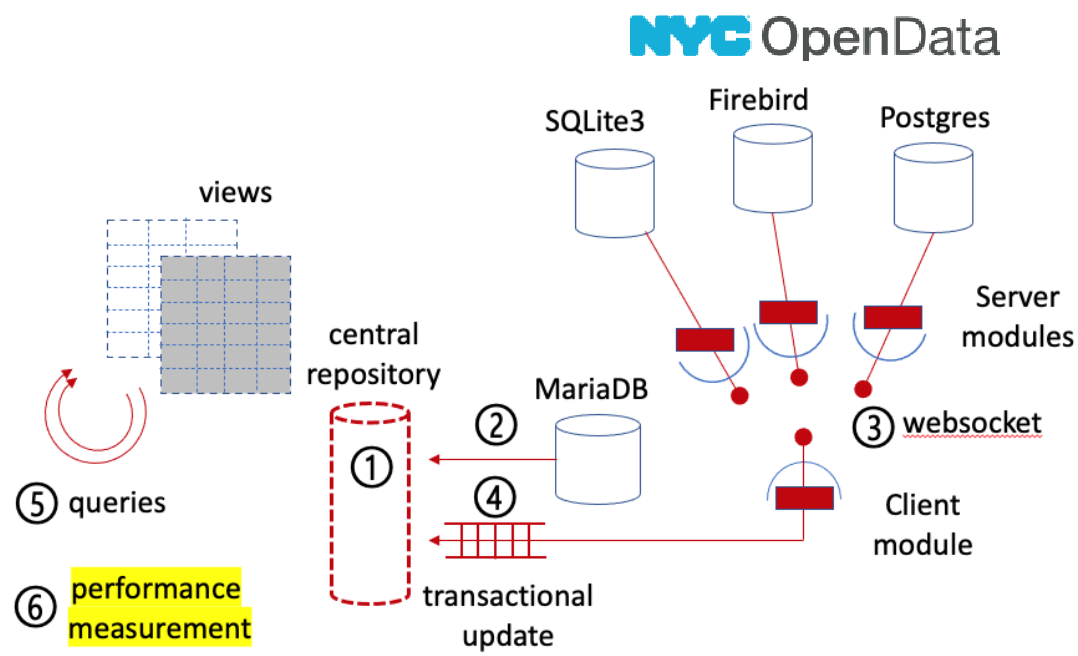
Task 4: Distributed Database using Hypercube (1/2)

Simulation Experiments

- Mininet/Openflow SDN for 2^4 node hypercube network
- 4 nodes with NYC OpenData instances
- Distributed query processing based on websocket
- Assessment of data exchange time: comparison to 4×4 node grid network
  - Difference not impactful; larger scale experiment underway





Task Members: Abbe Mowshowitz, Akira Kawaguchi (CCNY); Masato Tsuru, Shibata Masahiro (Kyutech)

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Task 4: Dynamic Systems Modeling (2/2)

Other Overlay Topologies

- Toroidal grid graph
- Kautz graph

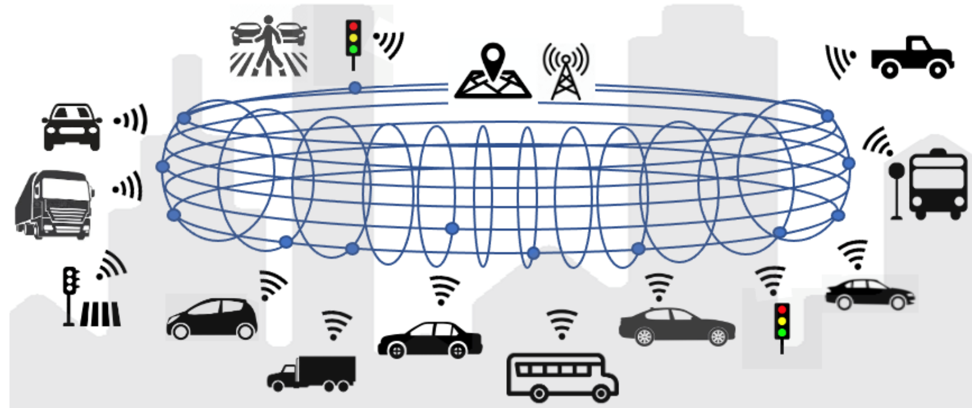
Desirable Properties

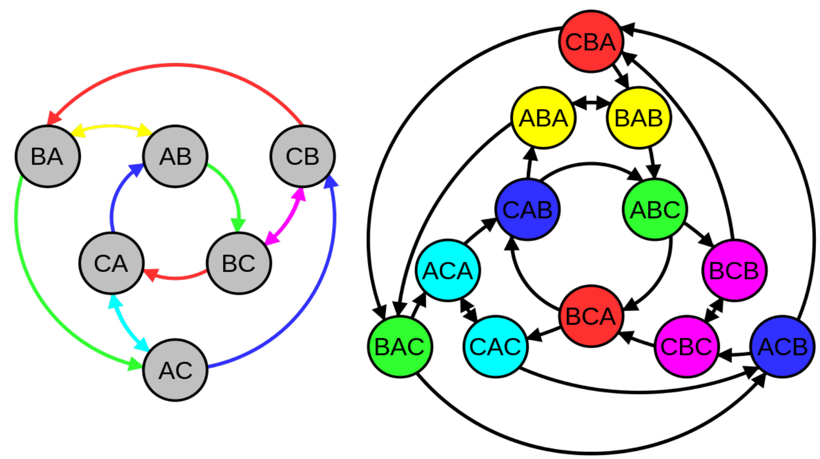
- Easy distance computation
- Resistance to attack
- Low cost maintenance

Applications

- Mobile systems
- Epidemiology

SDN Experiments in Plan





Wikipedia. Kautz graph, 2021

Future Directions

1) Continue the international cooperation between CCNY and Kutech

2) Continue Building the international testbeds;
   a. Kyutech-CCNY Testbed
   b. COSMOS CCNY node and Connection to Kyutech
   c. COSMIC connectivity
   d. NSF proposal for expansion of the CCNY testbed to other countries

3) Detailed experimentation on the International Testbed

Thank You