

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

October 26, 2018

Kazuya Tsukamoto

Masato Tsuru

Tarek Saadawi

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

**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 (Partners):

- **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, emulation and simulation of large scale Internet of Things (IoT) with application to smart grid (this is highlighted in the “**Testbed Experiments**” section)**

Intellectual Merit

- The traditional centralized architecture cannot accommodate such user demands due to **massive load** on the core network and **long latency**.
- Therefore new architectures, which bring network functions and contents such as **computing and communications to the edge of the network**, are proposed.
- This work will result in collaborative and fundamental research that will **advance the knowledge and know-how** in the field.

Broader Impact

- The proposed work is essential for resilient edge cloud/networking to make **the human society smarter and safer**.
- The proposed work will result in **numerous high-quality publications** that will maximize utility and reusability of our approaches.
- **Students** will be selected from a diverse pool, including internationally, and one aim of the project will be to **increase diversity** and the representation of women and minority in Engineering.
- This project will enhance scientific collaboration between **the two countries**.

Communications and Regular Meetings

- **Monthly Meeting with Video Conference**
(two meetings already; 9/ 20/2018 and 10/18/2018)
- **Setup URL at Kyutech for video conferencing**
- **Created a mail list for all team members**

Planned Visits

- **This Fall semester (Early December): Visit by Kyutech to CCNY**
- **Spring semester: Kyutech visit to CCNY (March 2019)**
CCNY visit to Kyutech (Early Summer 2019)
- **(Pre-award meeting was held in Japan in 6/18/2018)**

Task Coordinators

- **Each task (4+1) is assigned two coordinators; one from Kyutech and one from CCNY**



Pre-Award Meeting, June 18, 2018, Kyutech Institute-Japan

Left to Right: (KYUTECH-Japan) Professors Kenji Kawahara, Kenichi Kourai, Kazuya Tsukamoto, Eiji Hayashi, Masato Tsuru
(CCNY-USA) Abbe Mowshowitz, Tarek Saadawi, Myung Lee, Akira Kawaguchi

Not Present: Professors Takeshi Ikenaga, Daiki Nobayashi, Masahiro Shibata

NETS: JUNO2: RESILIENT EDGE CLOUD DESIGNED NETWORK

Tasks

➤ **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**

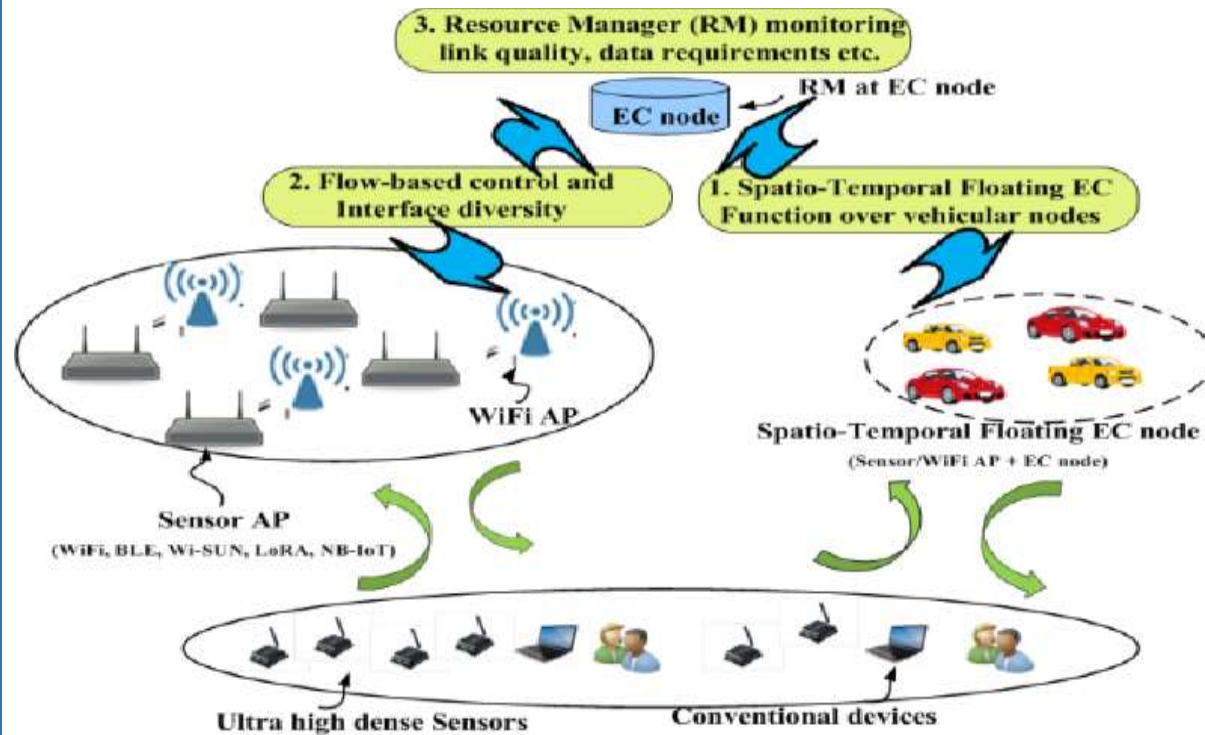
Task Members: **Abbe Mowshowitz**, Akira Kawaguchi (CCNY); Masato Tsuru, **Shibata Masahiro** (Kyutech)

➤ **TESTBED EXPERIMENTS** **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

T1: Resilient Resource Access for Massive End Devices



Concept of End-device networking

General Plan of Work

Step 1: introduce vehicular EC node to extend service coverage and to serve as temporal EC node, and apply the SDN function to floating EC node to allocate proper wireless resources to each of data flows. Also propose an algorithm for the RM to optimally allocate computing (VM) and bandwidth resources.

Step 2: extend the algorithms proposed in Step1 to consider the dynamic change in not only link quality but also communication traffic, and implements these methods as subsystems in the SDN environment.

Step 3: develop a structure for efficient integration of SDN control and RM decision. Furthermore, develop a failover scheme in which the running VMs can be migrated to nearby available EC nodes, to support reliable services.

Impact

- ✓ The distributed resilient EC system as a network of geographically distributed EC nodes, brokering between end-devices and Backend Cloud (BC) server offers the advantages for:
 - Fulfilling a diverse QoS requirement
 - Resiliency of computing and connectivity
 - Scalability to support massive number of end devices
- ✓ The distributed resilient EC system supports (1) coverage extension by introducing spatio-temporal floating EC nodes, (2) flow-based resilient communication between end-devices and an EC node via interface diversity, and (3) optimal resource allocation among end-device, EC, and BC to meet a diverse QoS requirements such as **latency and blocking rate**.

Milestones:

Year 1: Design and analysis of Resource Management Framework, which will be undertaken in the consideration of traffic demand and QoS, including a flow control algorithms.

Year 2: Performance evaluation and Software Development Analytical and simulation study for resource management for various EC scenarios.

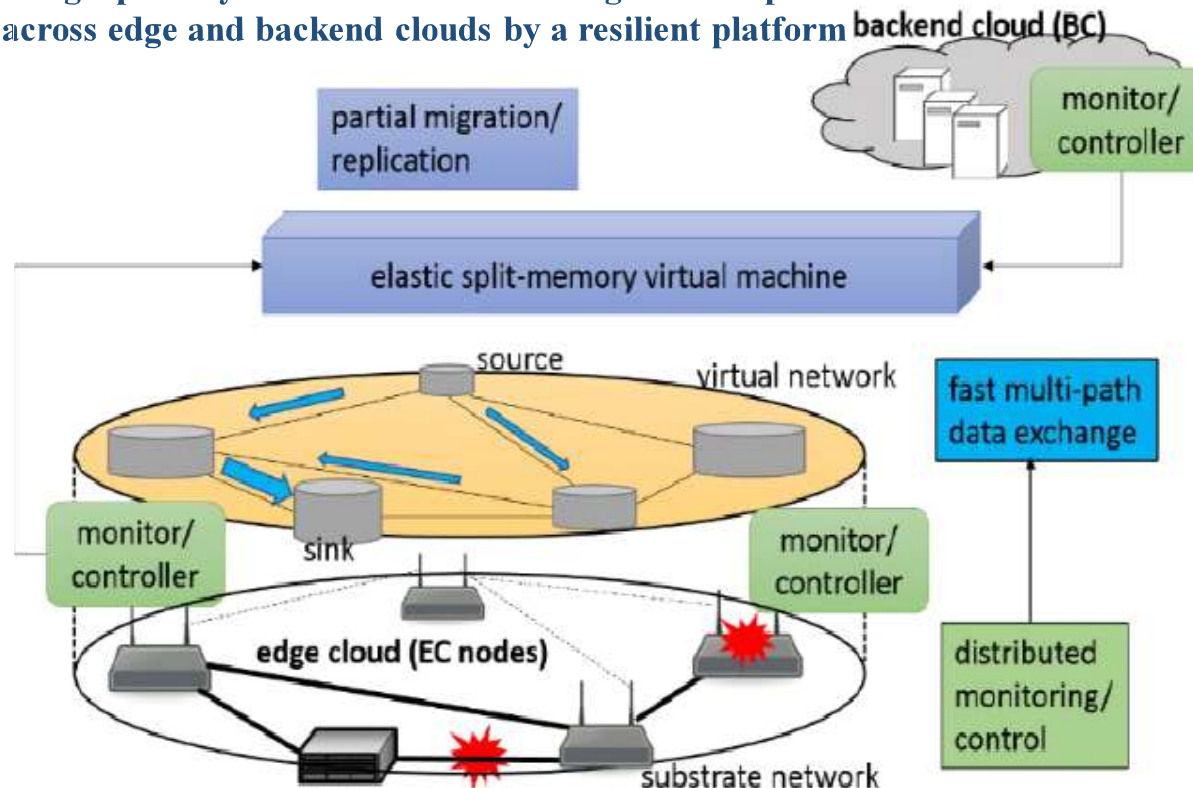
Year3: Results of steps 1 and 2 will be ported to the integrated testbed.

Task Members:

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

T2: VIRTUALIZED ADAPTABLE COMPUTING and NETWORKING

Geographically distributed data sharing and computation across edge and backend clouds by a resilient platform



General Plan of Work

Step 1: Develop the following OpenFlow-based network functions and Virtual Machine (VM)-based computation functions for adaptability.
 (T2-1) Fast multi-path data exchange among EC/BCs for migration and replication
 (T2-2) Distributed monitoring and control of links to detect and cope with degradation
 (T2-3) Elastic split-memory VMs in EC/BCs for partial migration and replication
 (T2-4) Distributed introspection and control of VMs to detect and cope with degradation

Step 2: Integrate the network functions and VM functions developed in Step 1. These functions are used in a distributed data sharing and computation platform with interfaces to other tasks (T1, T3, and T4) to realize effective interplays of those tasks.

Impact

- ✓ Distributed data sharing and computation can provide
 - * Shorter response times by access and processing proximity,
 - * Location-dependent services in a more efficient and robust manner.
- ✓ The proposed virtualized adaptive computing and networking platform is resilient to diverse and dynamically varying resources and demands for computation, storage, and communications, based on
 - * Intrinsic adaptability of **Virtual Machine (VM) and OpenFlow-based network**,
 - * Functions for **fast migration and replication** (T2-1, T2-3),
 - * Functions for **fast degradation detection and recovery** (T2-2, T2-4).

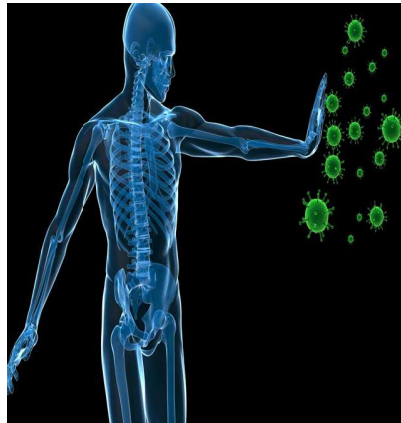
Milestones:

Year 1: Design and develop the key functions of each subtask in parallel.
Year 2: Develop and test the platform to combine the VMs and networks including the basic operation part and the management part in a lab environment.
Year 3: Evaluate the integration of Task 2 on the testbed experiments with some application scenarios.

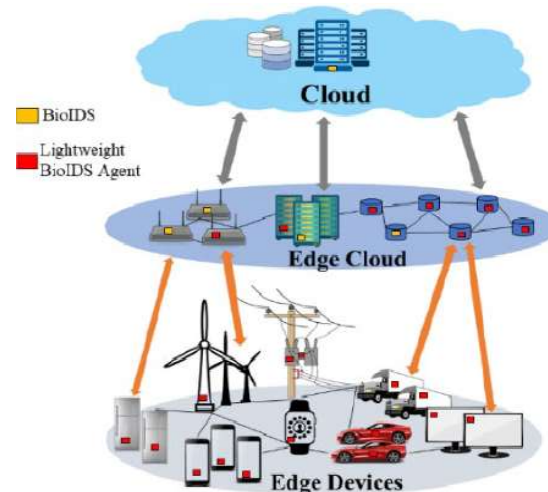
Task Members:

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

T3: A Bio-Inspired Intrusion Detection System (BIIDS) for Protecting IoT Devices



Artificial Immune System (AIS) Approach.



Architecture for IoT device/network security using BioIDS and lightweight agents.

General Plan of Work

Step 1: basic features are generated or extracted from ingress network traffic to the internal network where protected servers reside

Step 2: Signals that represent abnormal activities (danger signals) and normal activities (safe signals) are generated using the features extracted in Step 1.

Step 3: In the training phase, the NSA instances that make up the NSA module are trained using the two signals generated in Step 2.

The decisions made by the constituent NSA/DCA modules are weighted (using the weights determined during the training phase) and used by the decision-making module to distinguish DoS attacks from legitimate traffic.

Impact

- ✓ A tool which makes use of the algorithms that exist in an area under artificial intelligence known as artificial immune system (AIS) to provide unified infrastructure for insider/outsider threat detection in:
 - Smart Grids
 - Enterprise Networks
 - Connected Autonomous Vehicles
 - Mobile Adhoc Networks
- ✓ For its insider threat prediction capability, it supports Quick Search for any specific user based on name and other diverse search criteria or options.

Milestones:

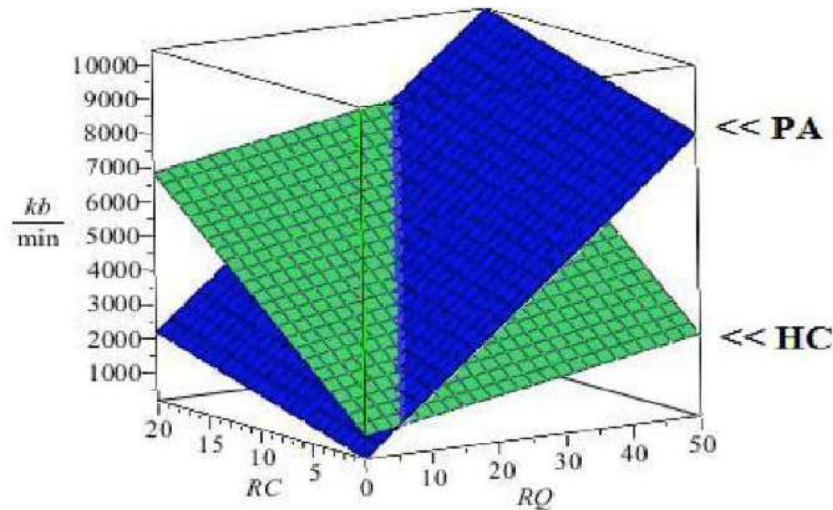
- ✓ Year 1: detailed analyses of IoT device/network attack surfaces
- Year 2: developing a lightweight software agent that will run on IoT devices/edge-cloud nodes especially on those that have constraints on memory and processing capability.
- Year 3: perform penetration testing in real-time against the IoT devices or cloud/edge-cloud nodes using the information and vulnerability analysis results obtained

Task Members:

Tarek Saadawi (CCNY), Kenichi Kourai (Kyutech)

T4: DISTRIBUTED DATABASE USING HYPERCUBE

Engineered Hypercube vs. Random Network



General Plan of Work

Step 1: Create a hypercube version of the open source GaianDB and populate it with equipment data from the use case connected with an electric utility. The engineered hypercube (colored green in the diagram) has a clear advantage when the rate of change in the network structure is relatively low and the query rate is relatively high.

Step 2: Implement the database developed in Step 1 as a subsystem in a software defined network environment.

Step 3: Develop strategies for optimal querying in the hypercube system. In particular, determine feasibility of designating network nodes as temporary processing centers for query operations such as join and semijoin.

Impact

- ✓ An engineered hypercube as an overlay network in a dynamic, distributed database is an efficient system for querying under certain conditions, and offers the advantage of substantial reductions in network traffic and thus lowers bandwidth utilization.
- ✓ Implementation in a software defined network environment will make the engineered hypercube into an efficient and practical distributed database tool.

Milestones:

Year 1: Design and development a distributed query optimizer. The target application will be designed to gather data for real-time analysis and monitoring.

Year 2: Hypercube database and query optimizer will be integrated into subsystem by means of software-defined networking.

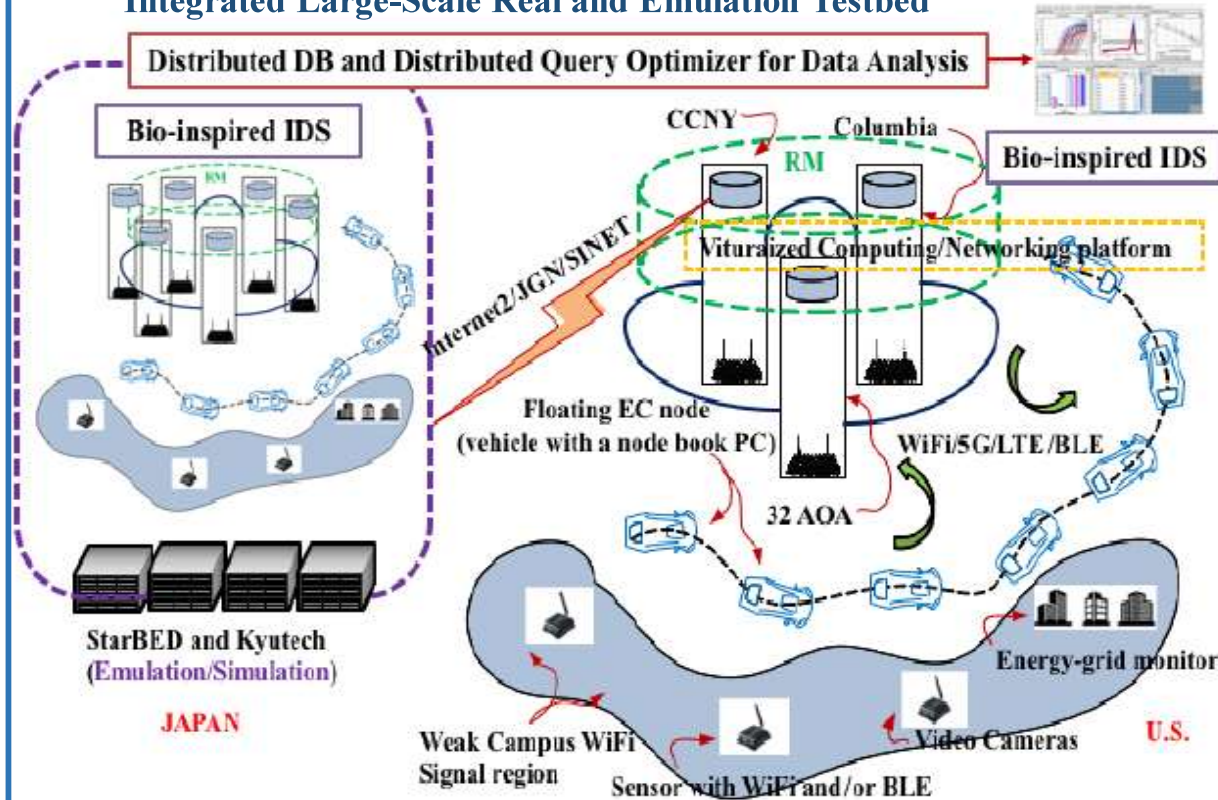
Step 3: Results of steps 1 and 2 will be ported to the integrated testbed with other subsystems.

Task Members:

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

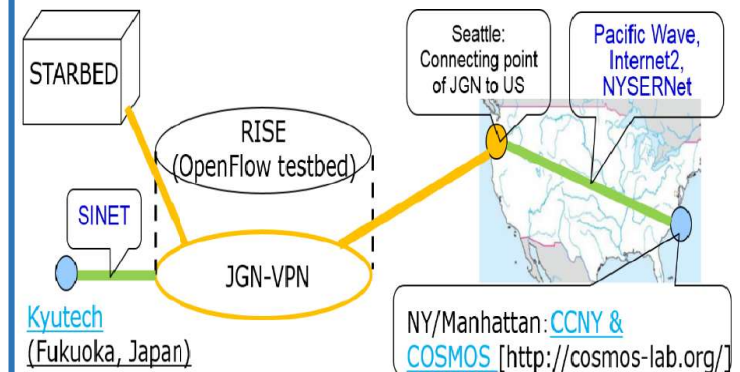
TESTBED EXPERIMENTS

Integrated Large-Scale Real and Emulation Testbed



General Plan of Work

Step 1: Build the testbed environments, i.e., networking and computing resources, with int'l collaborations.
Step 2: In parallel, select use-case applications (e.g., Distributed electric-power grid, Smart-city person identity by facial recognition). Then design, develop, and test the experimental scenarios.
Step 3: Conduct the experimental evaluations on the integrated testbed across US and JP.



Impact

- ✓ An integration across a real city-scale testbed in US (**COSMOS**: Cloud Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment) and a large-scale emulation/simulation testbed in JP (**StarBED**) realizes a single global edge-cloud networking testbed based on cutting-edge technologies with diversity and programmability.
- ✓ Use-case experiments on some realistic IoT applications running on the testbed involve the key functions developed in four tasks.
- ✓ Such testbed experiments can evaluate the feasibility and effectiveness of the proposed **Resilient Edge Cloud Designed Network**, and also clarify the remaining issues.

Milestones:

Year 1: Kyutech-RISE/StarBED/Seattle connections. Use-case applications selection.
Year 2: Kyutech-CCNY connection. Design and development of the experiments with feedbacks to each task.
Year 3: The total testbed experiments.

Task Members:

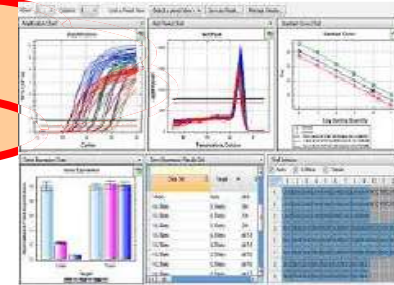
Myung Lee and all other members in CCNY;
 Masato Tsuru and all other members in Kyutech

Summary

Backend-Cloud

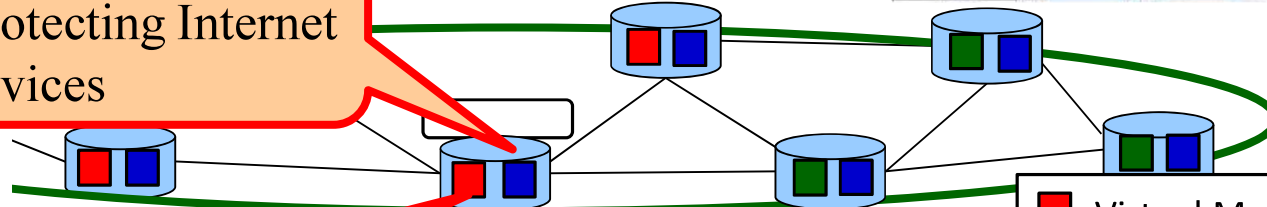


Task4: Distributed Database using Hypercube



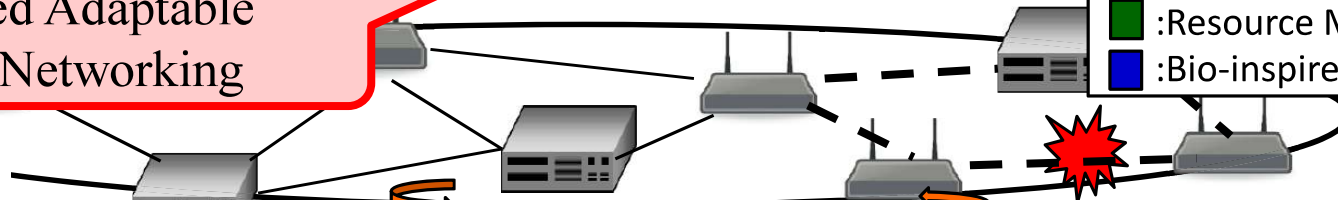
Task3: Bio-Inspired Intrusion Detection System (BIOIDS) for Protecting Internet of Things Devices

Virtual Network



Task2: Virtualized Adaptable Computing and Networking

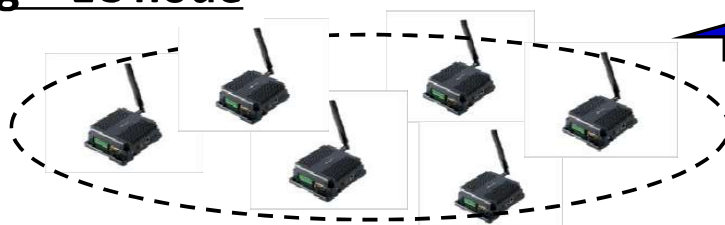
Edge-Cloud



Task1: Resilient Resource Access for Massive End Devices

Various wireless access (Wi-Fi/5G/LTE/BLE)

Floating EC node



TE: Testbed Experiments

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

October 11, 2019

Tarek Saadawi
Kazuya Tsukamoto
Kenichi Kourai

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 (Co-PI)
- 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, 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 with Video Conference**
- **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)**

Kyutech Campus (June 2018)



Pre-Award Meeting, Kyutech, Japan

CCNY Campus (March 2019)



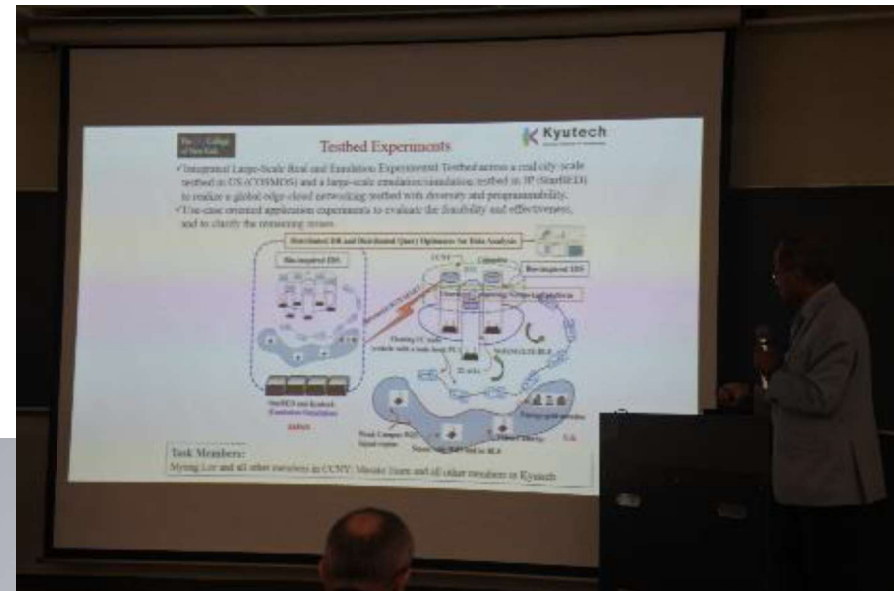
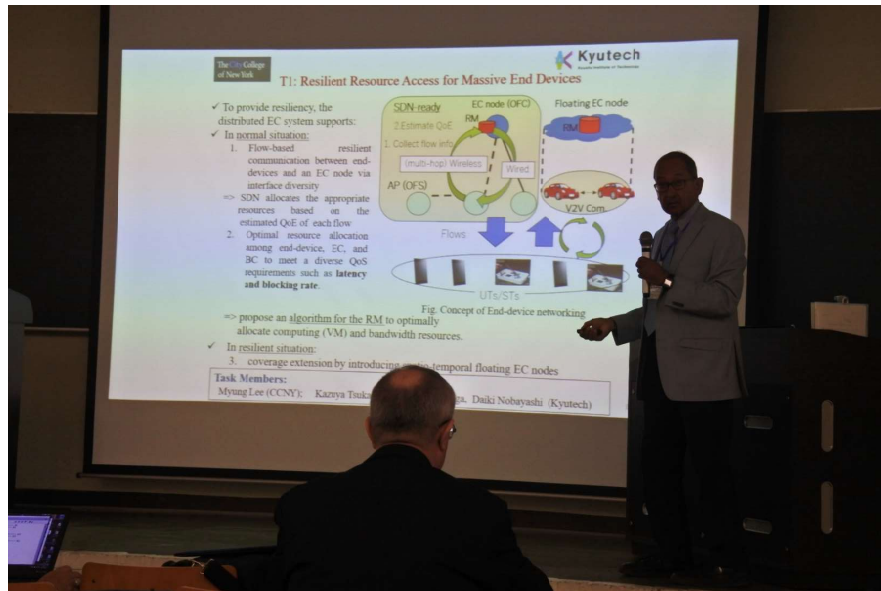
Kyutech Campus (September 2019)



Accomplishments

- Keynote
 - T. Saadawi, “Secure Resilient Edge Cloud Designed Network,” INCoS 2019
- Journal
 - T. Saadawi , A. Kawaguhi, M. Lee, A. Mowshowitz, “Secure Resilient Edge Cloud Designed Network,” IEICE Transactions on Communications, accepted (invited paper)
- International Conference
 - 22 papers
- International Workshop
 - 7 papers
 - JUNO2 session in WIND 2019
- Local Workshop in Japan
 - 17 papers

Keynote at INCoS/NBiS 2019

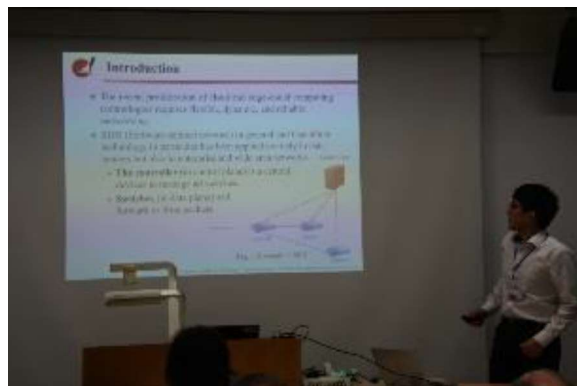
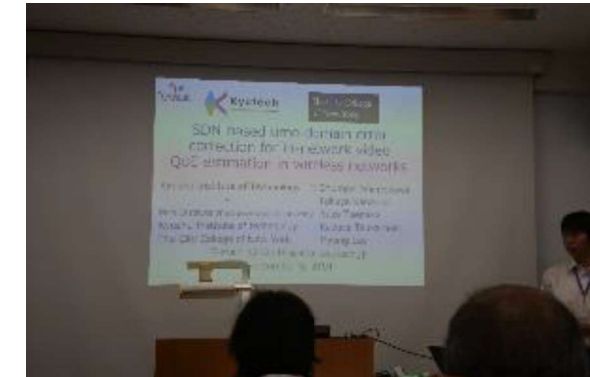


WIND 2019: JUNO2 Session

• Prof. Myung J. Lee



• Kyutech students



- 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”



Best Paper Award in INCoS/NBiS 7 Workshops

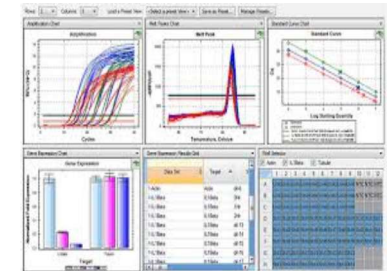


Overview of RECN

Backend-Cloud



Task4: Distributed Database using Hypercube



Task3: Bio-Inspired Intrusion Detection System (BIOIDS) for Protecting Internet of Things Devices

Virtual Network

Task2: Virtualized Adaptable Computing and Networking

Edge-Cloud

Task1: Resilient Resource Access for Massive End Devices

Various wireless access (Wi-Fi/5G/LTE/BLE)

Floating EC node



TE: Testbed Experiments

Legend:
■ :Virtual Machine
■ :Resource Manager
■ :Bio-inspired IDS

Tasks

➤ 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 (Kyutech)**, **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.

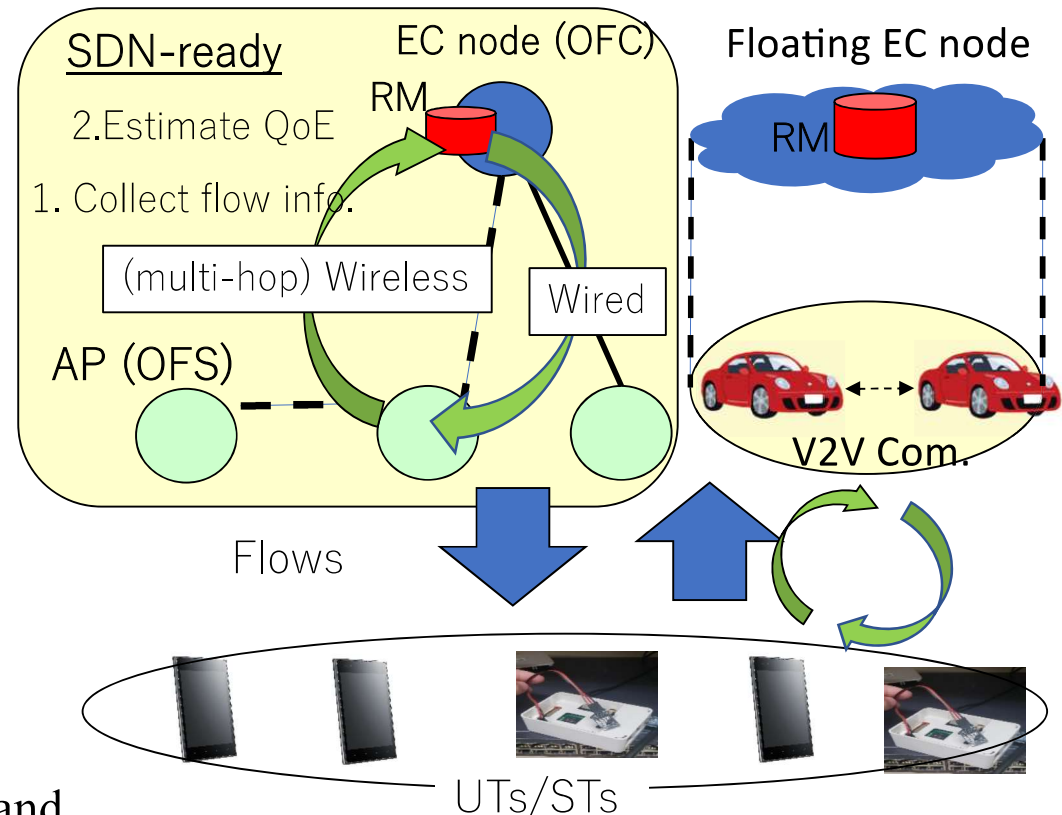


Fig. Concept of End-device networking

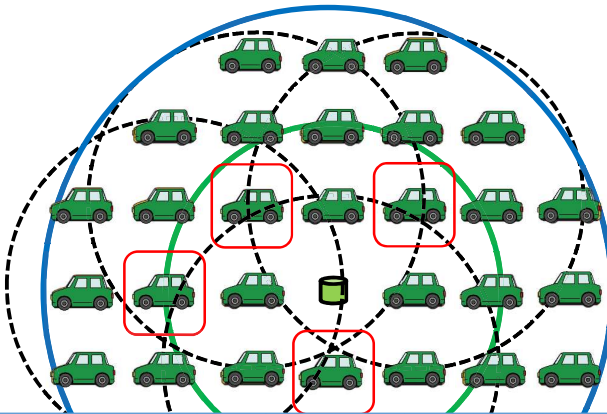
- ✓ In resilient situation:
 3. coverage maintenance/extension by introducing spatio-temporal floating EC nodes

Task Members:

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

- 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).
 - Each retaining data (or functions) have characteristics such as **timeliness and validity period** => we introduce **diffusion limit and a retention limit**.
 - We propose appropriate data transmission scheme based on data characteristics for the data retention system.
 - 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

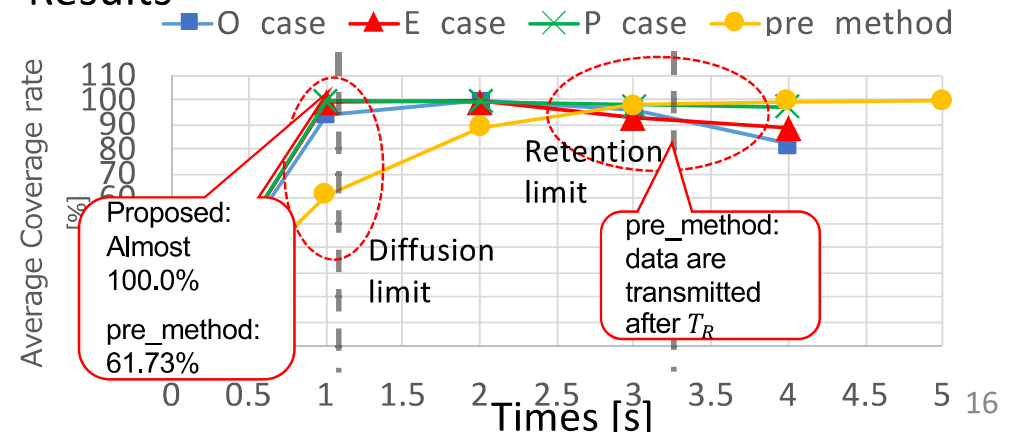


Achieving data retention efficiently based on the data characteristics by transmission control of our proposed scheme

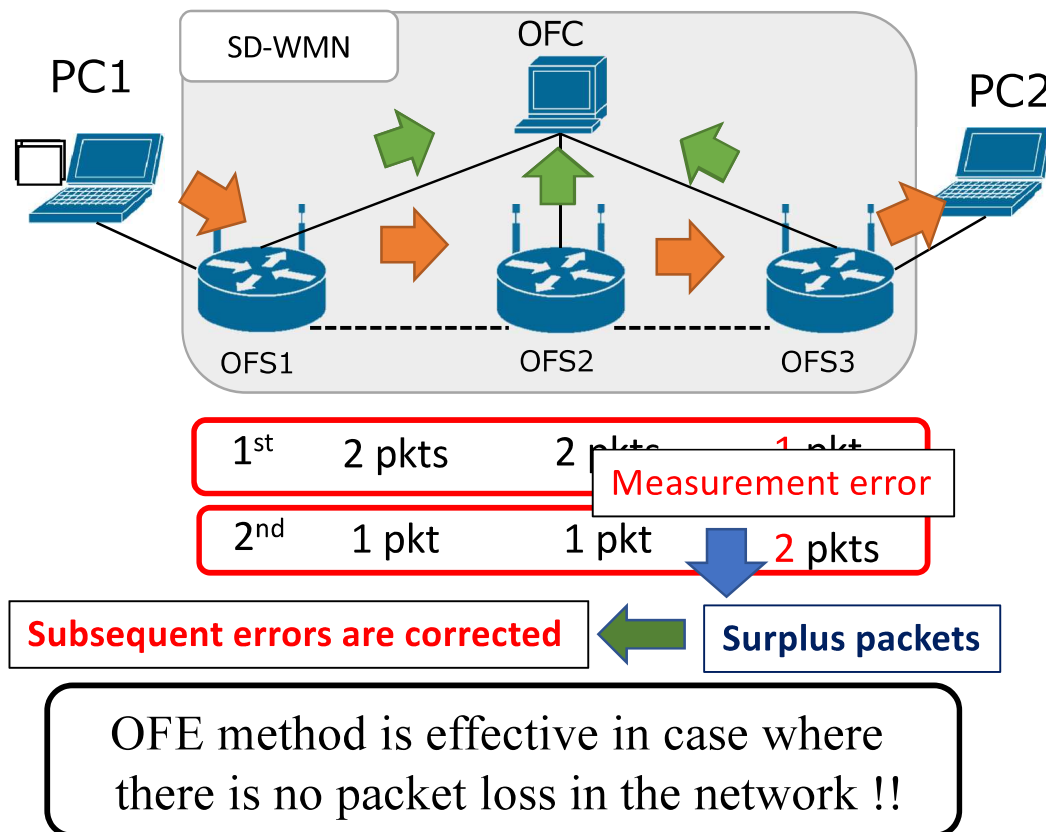
Experiment

- We evaluate our proposed scheme using the network simulator Veins (OMNeT++ and SUMO).
- We evaluate the time required for data spreading.

Results

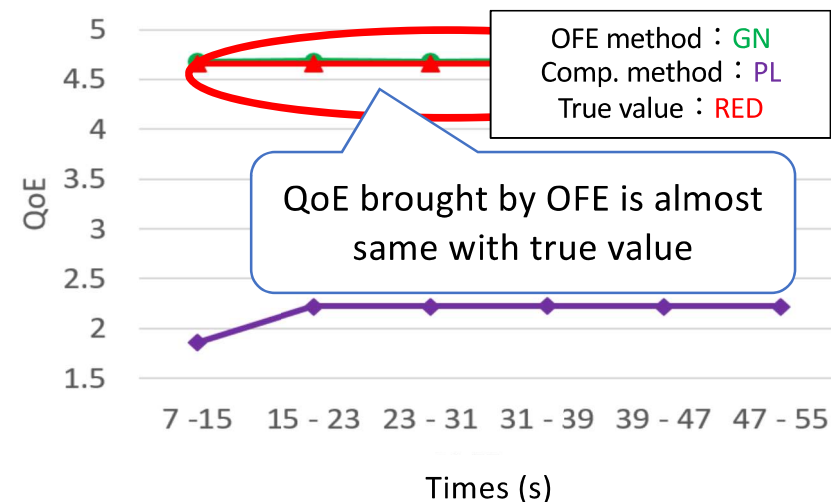


- We propose OFE (Openflow-based estimation) method
 - We use **video streaming app**. (G.1071 standard).
 - Measured parameters: (1) Throughput, (2) Packet loss ratio.
 - Video bitrate, Resolution, and frame rate are estimated based on (1) throughput
 - Since **measurement error inherently occurs** due to the different retrieval timing of FlowStats, packet loss ratio is corrected by using the accumulated surplus packets
 - Surplus packets = (# of pkts of receiver-side) – (# of pkts of sender-side)**



- Experiment
 - PC1 sends video flow to PC2 via 1 (2) hop wired/wireless link(s)
 - No packet loss in the network**
 - OFC estimates its QoE value based on the OFE method

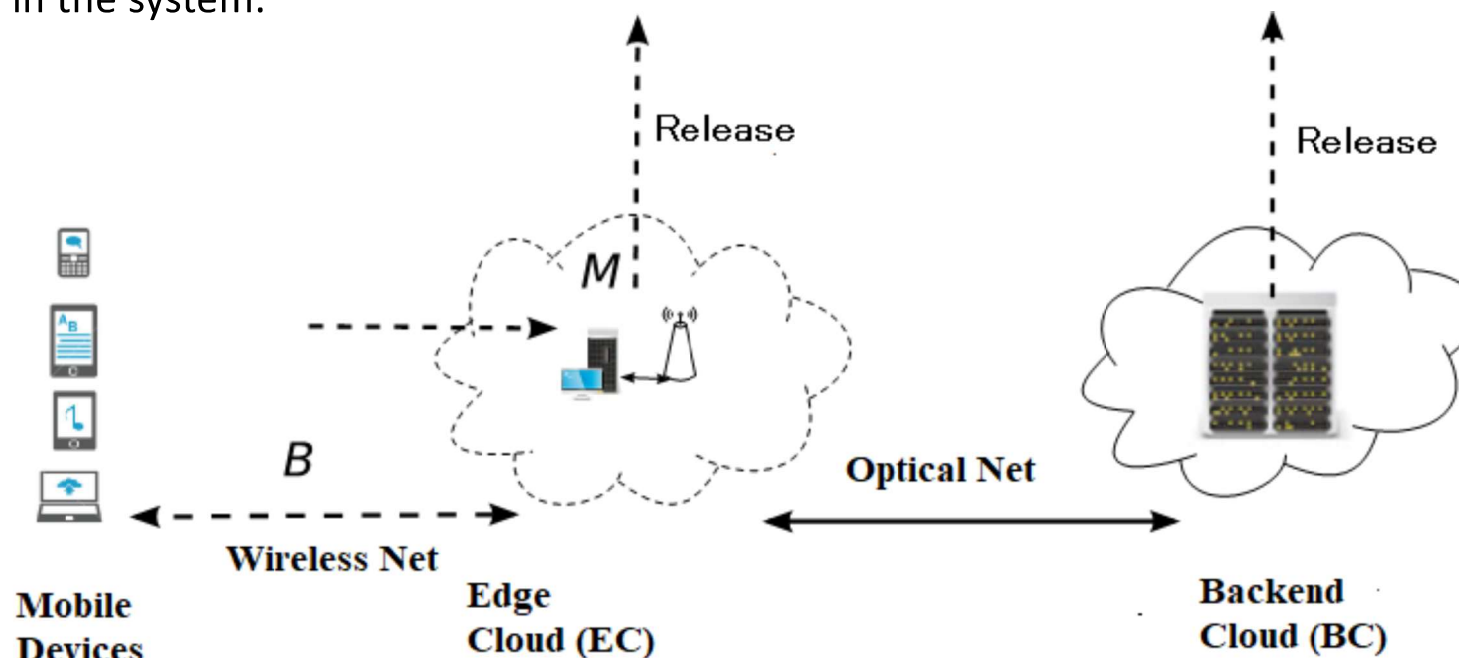
Results



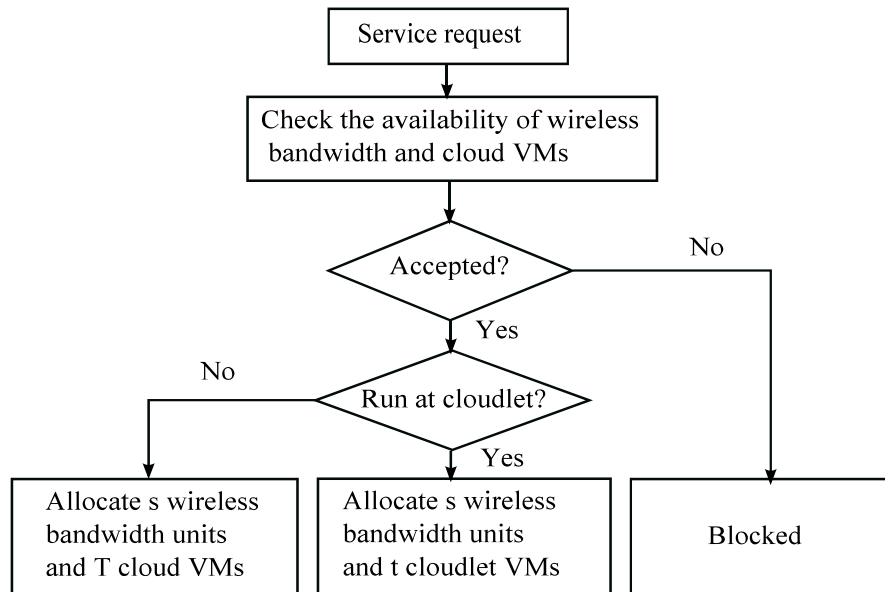
Abstract:

Mobile cloud computing utilizing edge cloud is an emerging technology to improve the quality of mobile services. In order to manage the computational capability of edge cloud and the wireless bandwidth between mobile devices and the edge cloud, we consider the multi-resource allocation problem for the edge cloud environment with resource-intensive and latency-sensitive mobile applications.

The proposed SMDP-based multi-resource allocation (SMDP-MRA) strategy enhances the quality of mobile cloud service, in terms of the system throughput (the number of admitted mobile applications) and the service latency. Through maximizing the long-term reward while meeting the system requirements of the request blocking probability and service time latency, an optimal resource allocation policy is calculated based on SMDP model. From simulation result, it is indicated that the system adaptively adjusts the allocation policy about how much resource to allocate and whether to utilize the distant cloud according to the traffic of mobile service requests and the availability of the resource in the system.



• Problem Statement



► SMDP based Multi-resource Allocation (SMDP-MRA)

State: [#VMs in EC and BC, Wireless BW, current utilization, *event*]

event {arrival, departure from EC or BC}

Action: {accept by EC or BC, reject}

Reward to consider

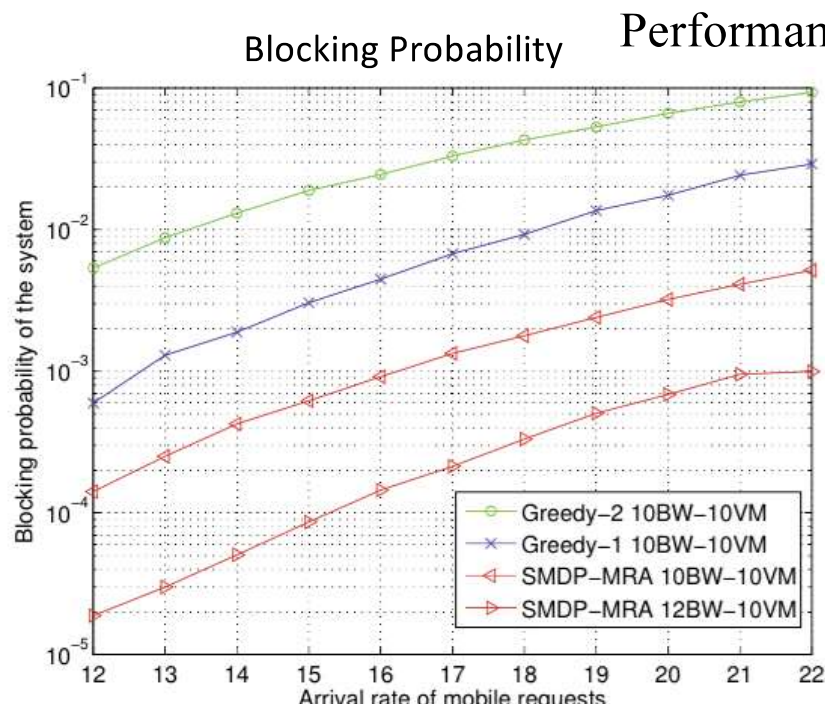
Efficiency of EC (low latency);

Resource availability;

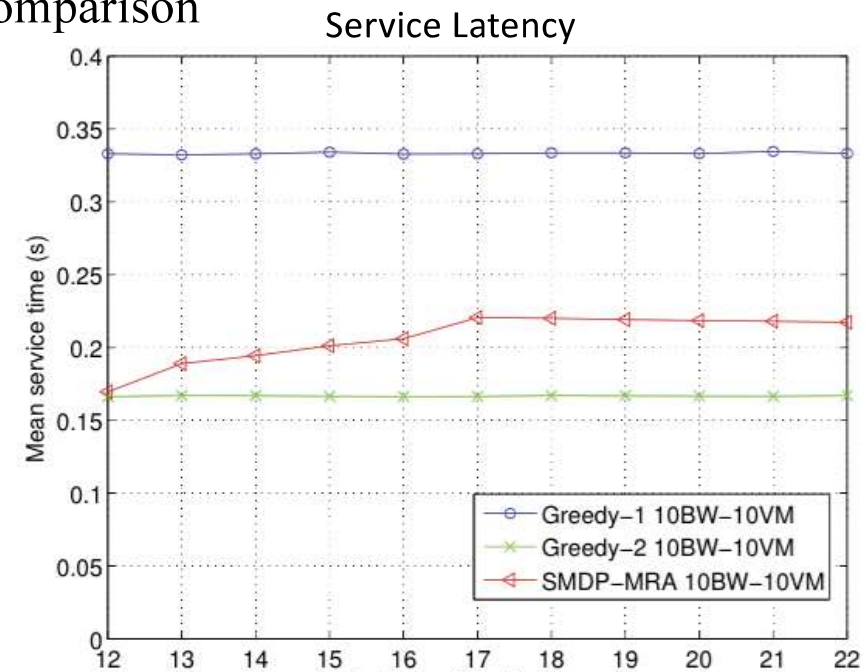
Cost of Service time (C_t)

Computation:

Linear programming



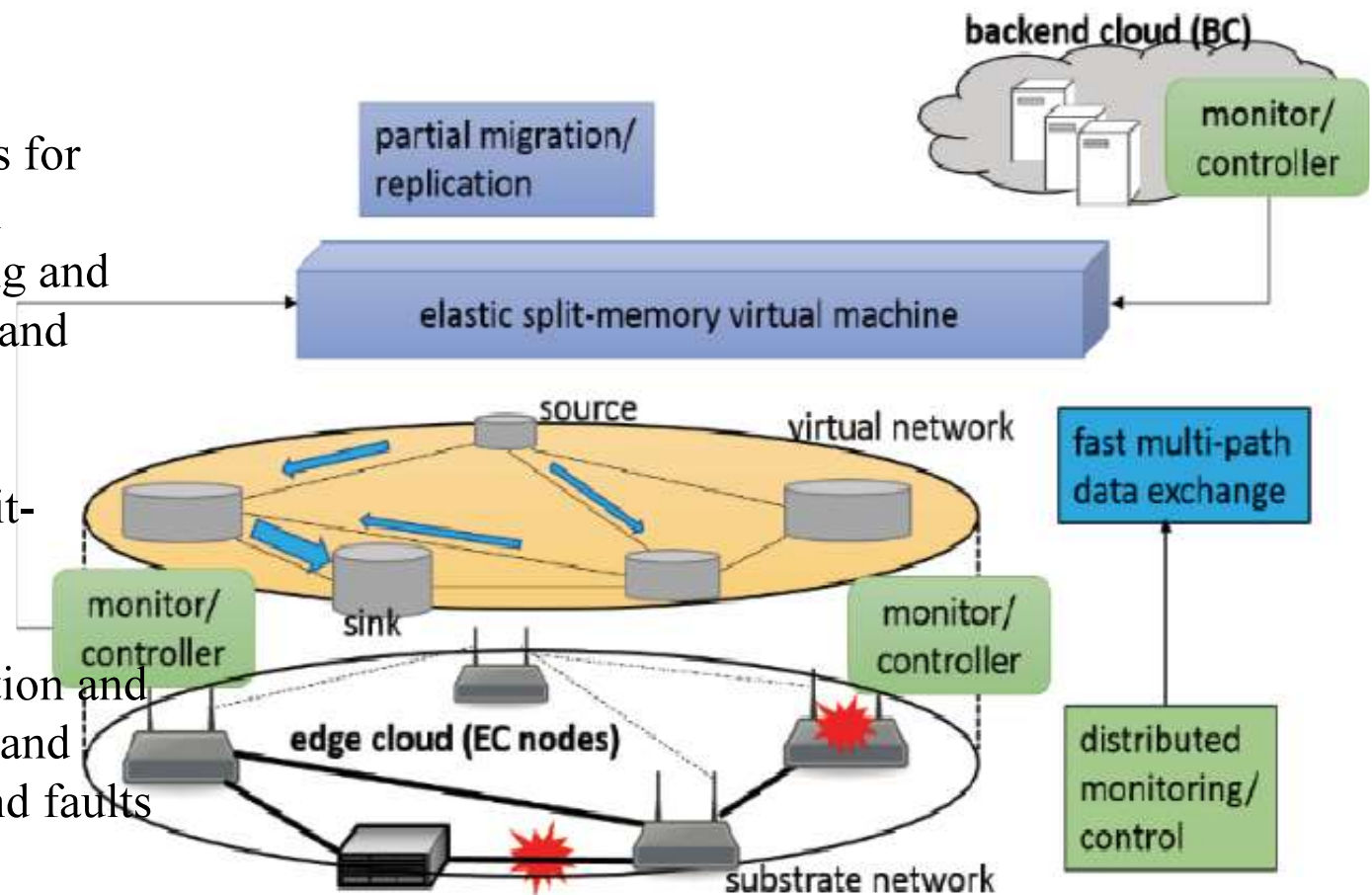
Performance Comparison



T2: 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

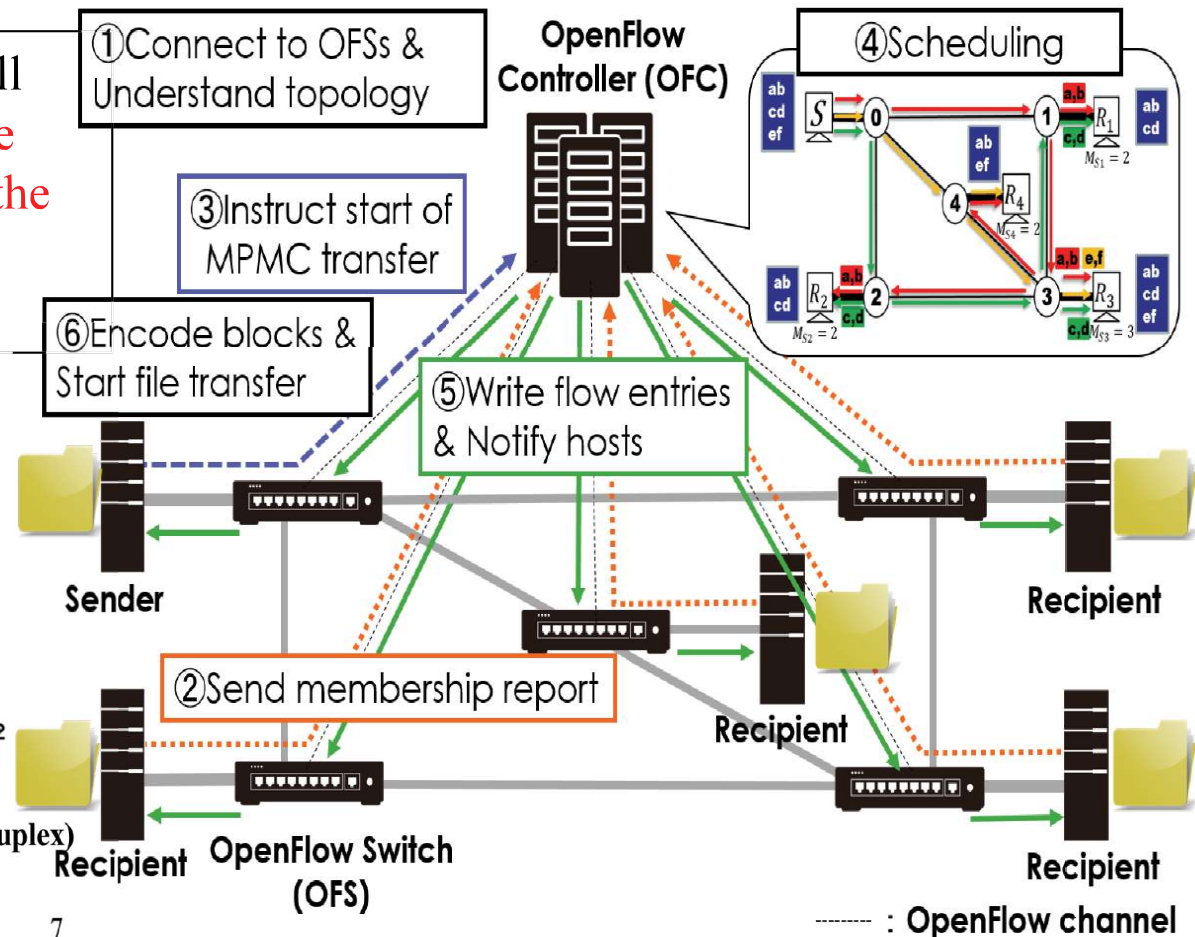
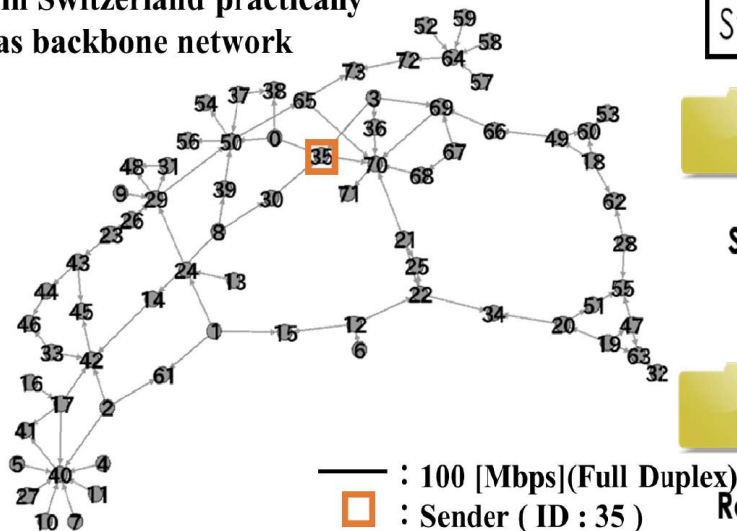


Task Members: Akira Kawaguchi, Abbe Mowshowitz (CCNY); Masato Tsuru, Kenichi Kourai, Kenji Kawahara, Masahiro Shibata (Kyutech)

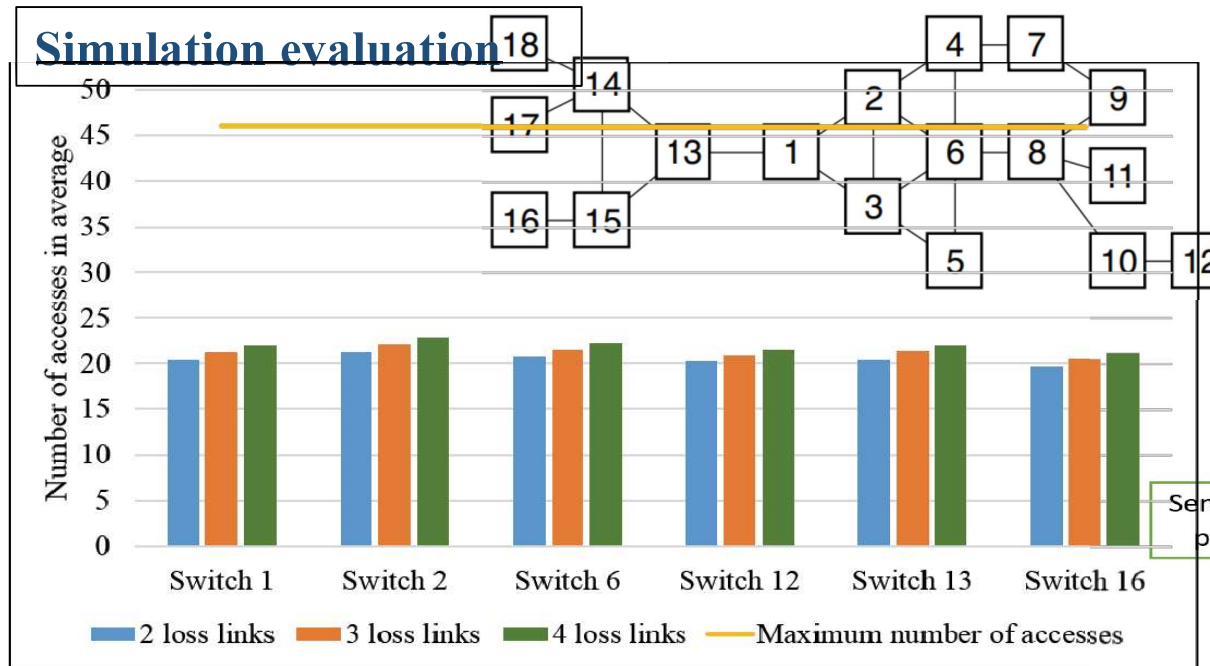
- ✓ Delivering a large file to many heterogeneous recipients on full-duplex **OpenFlow (OF)** network fast and efficiently; the schedule is computed and directed by the **OFController**.
- ✓ Proposal: **Coded-MPMC** = (1) **Multipath, multicast, and multiphase** delivery of file blocks from the **sender** to each **recipient** over its **max-flow paths** + (2) **Reed-Solomon coding** of blocks at the sender + (3) **Heuristic search of better block allocations** on the max-flow paths.
- ✓ Minimize the file retrieval completion time (RCT) of each recipient.

Simulation evaluation: In almost all cases, Coded-MPMC can achieve the **theoretical lower-bound of RCT** (= the file size / its max-flow capacity) for every recipient.

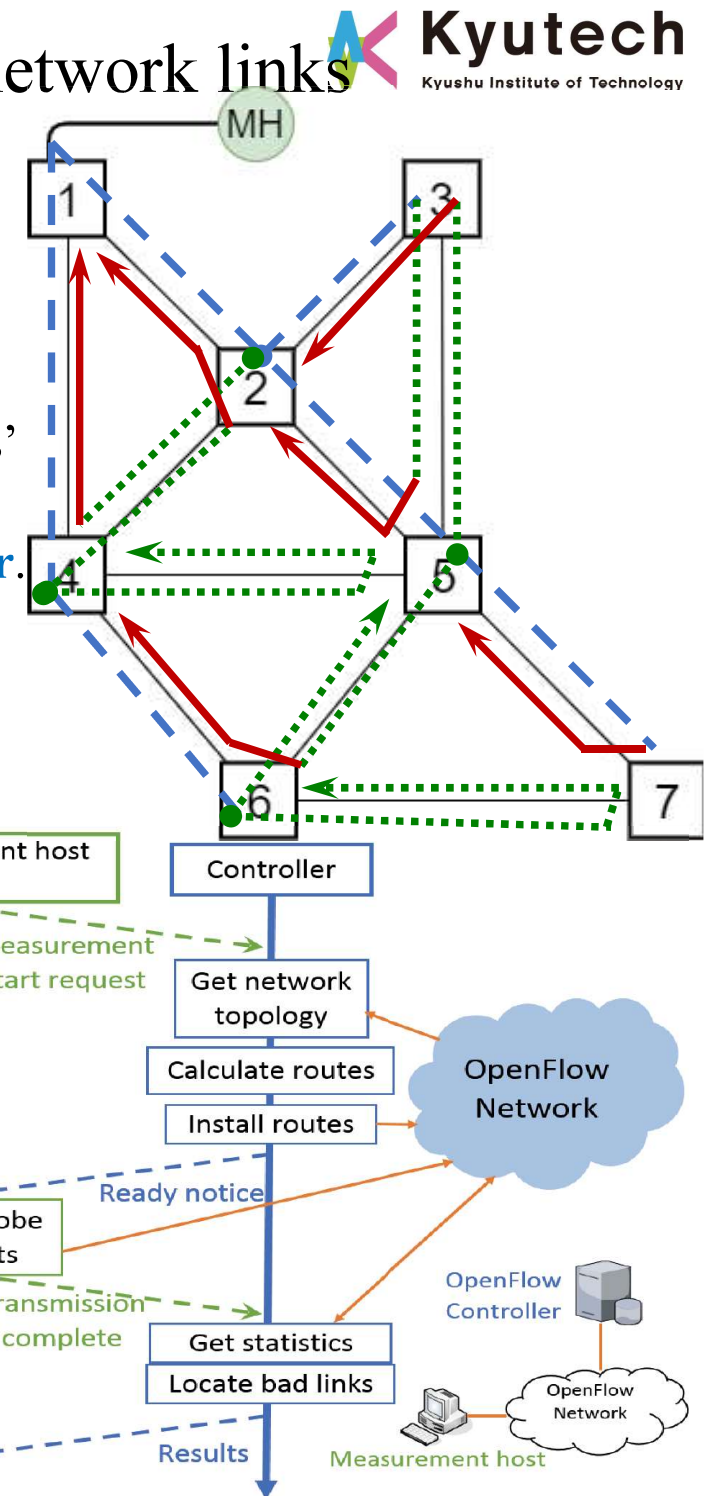
Used in Switzerland practically as backbone network



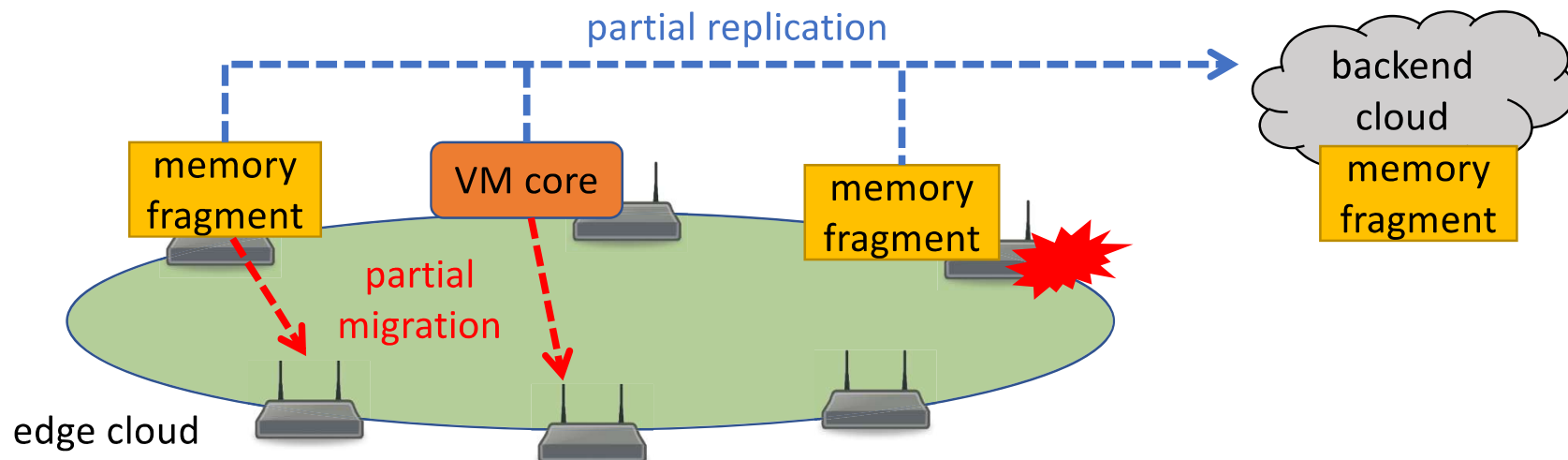
- ✓ Monitoring both directions of all links of **full-duplex OpenFlow (OF)** network and **locating all the high-loss links** fast and efficiently.
- ✓ Proposal: (1) Active **probe packets** from **MH** along a **multicast route** + (2) Passive monitoring of the probe packets' **flow stats** at each **OFSwitch** + (3) Selective **collection of the monitored stats** and **detection of lossy links** by **OFController**.
- ✓ Minimizing the number of accesses from OFC to OFSs (for stats collection) until all lossy links are located.



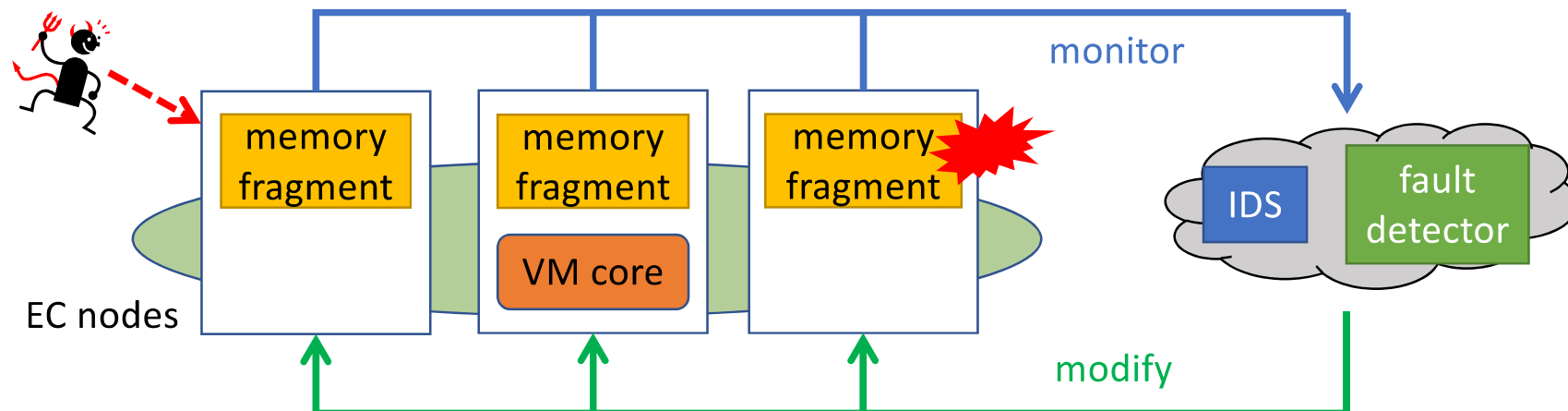
The number of necessary accesses to OFSs is less than half of the number of links regardless of different MH locations



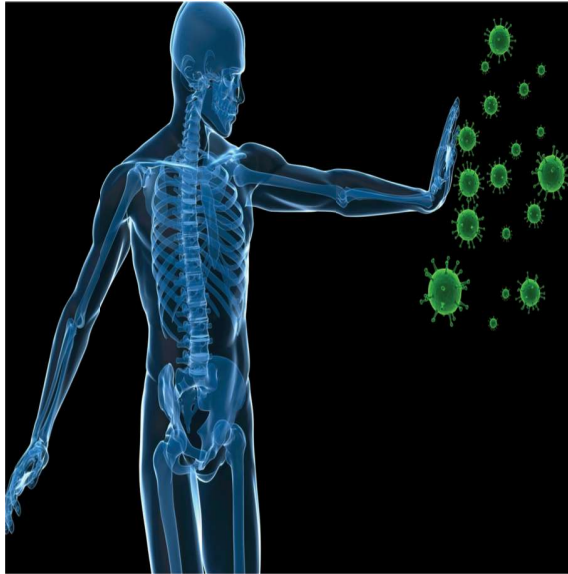
- Develop **split-memory VMs** efficiently running across EC nodes and BC
 - A split-memory VM consists of a VM core in one node and memory fragments in multiple nodes to use a large amount of memory
 - We achieved efficient split-memory VMs without transferring unused memory data
- Enable **partial migration** of split-memory VMs
 - Move a VM core and/or memory fragments from overloading nodes to others
 - We achieved two migration methods for substituting a node and merging all nodes
- Perform **partial replication** of split-memory VMs
 - Replicate a VM core and memory fragments independently against node failures
 - We achieved efficient checkpoint and restore of VMs



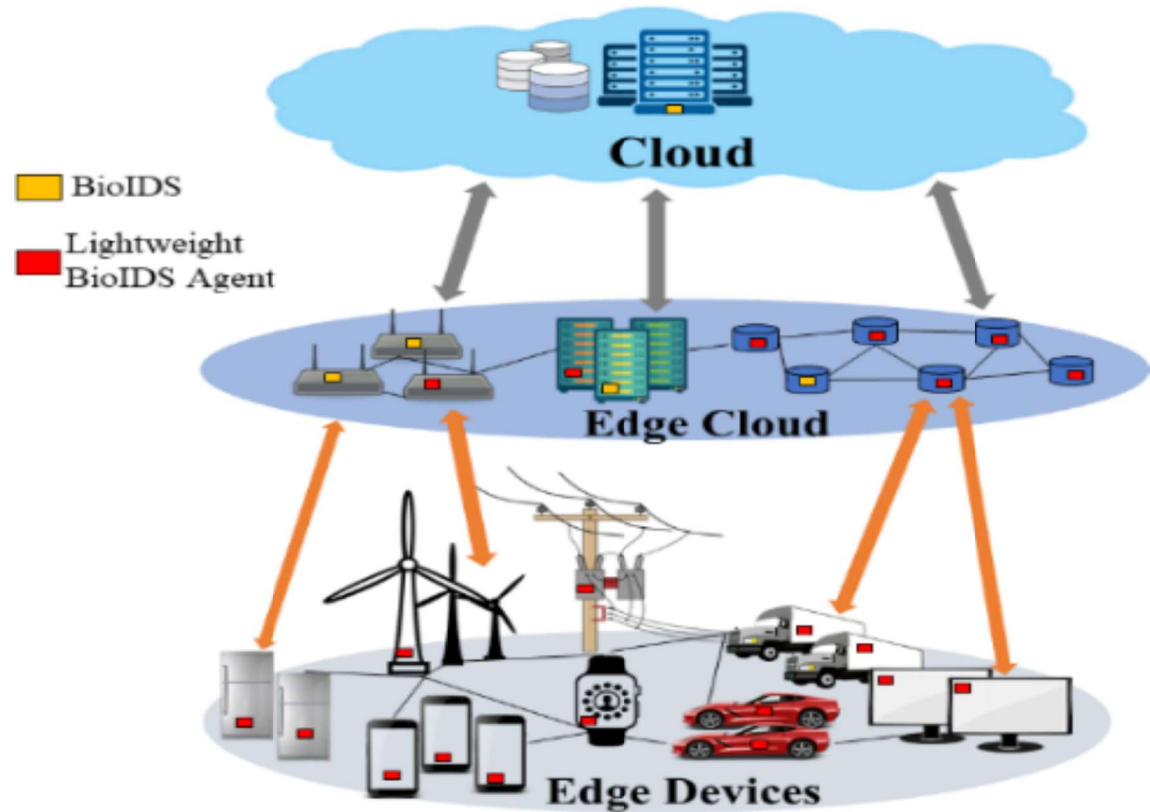
- Develop a **distributed introspection** mechanism of split-memory VMs
 - Distributed introspection enables monitoring the internal state of a split-memory VM outside the VM
 - Analyze the memory of a split-memory VM across multiple nodes transparently
- **Detect intrusion** into VMs and **faults** inside VMs
 - We enabled monitoring OS data in split-memory VMs
 - E.g., CPU/memory utilization, running processes, network usage, etc.
- **Recover** from intrusion and faults if possible
 - Modify OS data in the VM
 - E.g., changing CPU scheduling, disabling TCP connections, etc.



T3: A Bio-Inspired Intrusion Detection System (BIIDS) for Protecting IoT Devices



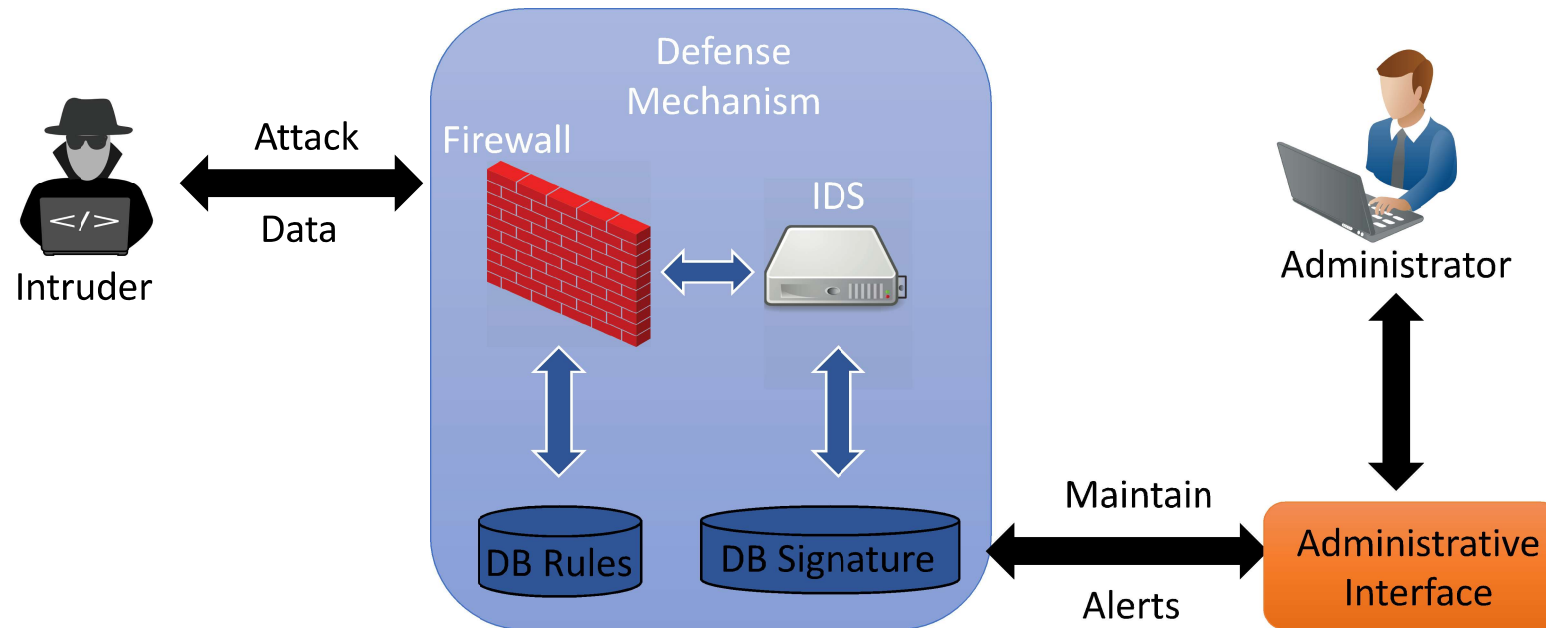
Artificial Immune System (AIS) Approach.



Architecture for IoT device/network security using BioIDS and lightweight agents.

Intrusion detection system

STANDART MODEL



Current Solutions to the Security Challenges of Internetworking

- ❑ Firewalls, IPSEC, VPN/tunneling
- ❑ Security Policies
- ❑ Intrusion Detection Systems (IDSs)

- **Signature-Based IDS** – Match all incoming traffic with signatures stored in a database. If a traffic matches, then its an attack (SNORT, BRO IDS).
- **Anomaly-Based IDS** – Learn accepted network behavior, then use this learned behavior to identify future behaviors that do not conform to this baseline.



Firewall

Artificial Immune System Approach

- Based on human immune system (HIS)
- Fully distributed and hence no central controller
- Only informs the agents of actual intrusions
- Uses genetic algorithm (GA) based on negative selection algorithm (NSA)

Advantages of the Immune System Approach

- Based on the Human Immune System.
- Distributed and Effective in Large Networks.
- Detects Zero-day attacks and Insider Threats.



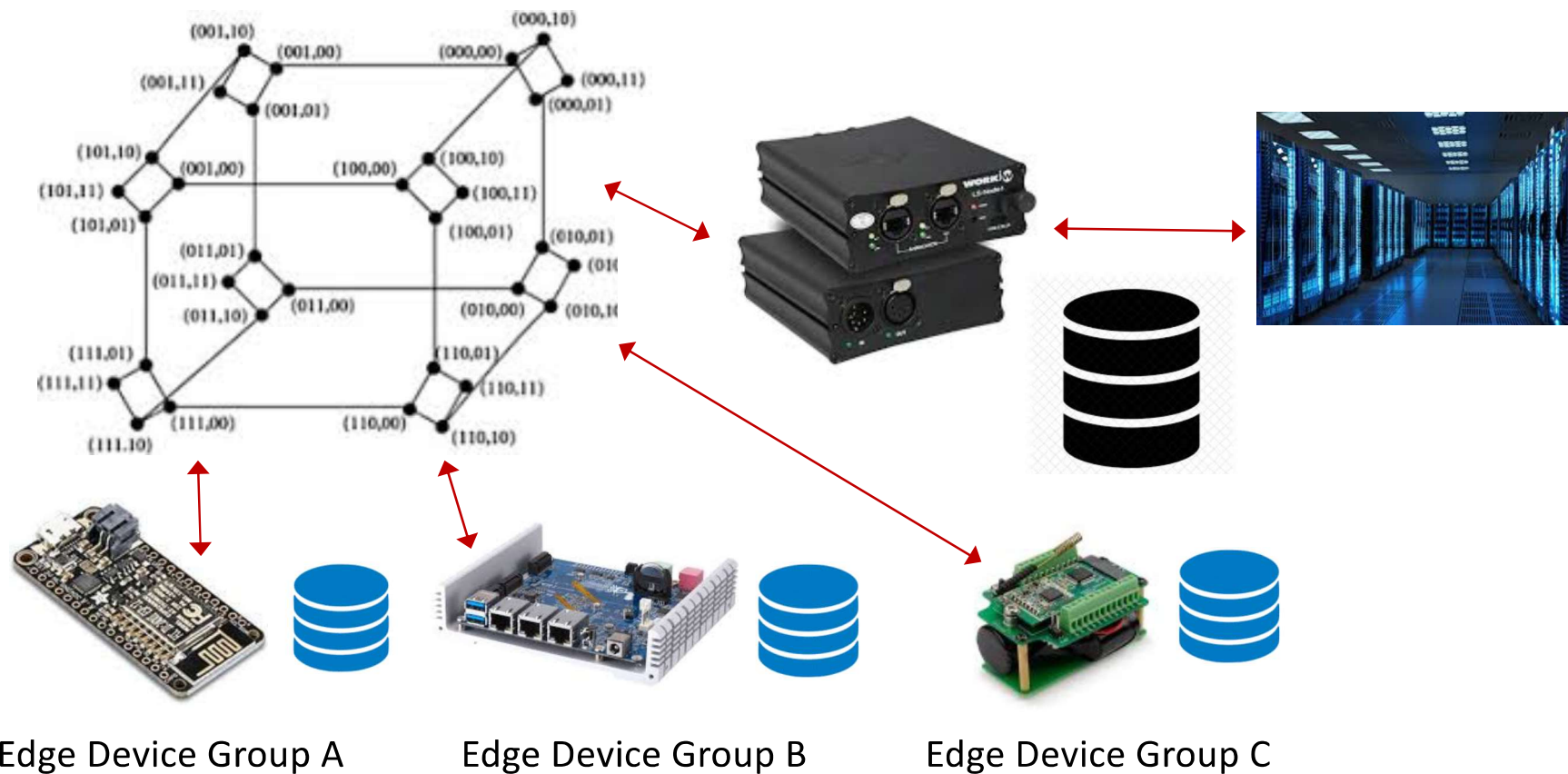
T4: Embedded hypercube database as subsystem in SDN

ENGINEERED NETWORK

Embedded Hypercube Network

Intelligent & Decision Systems

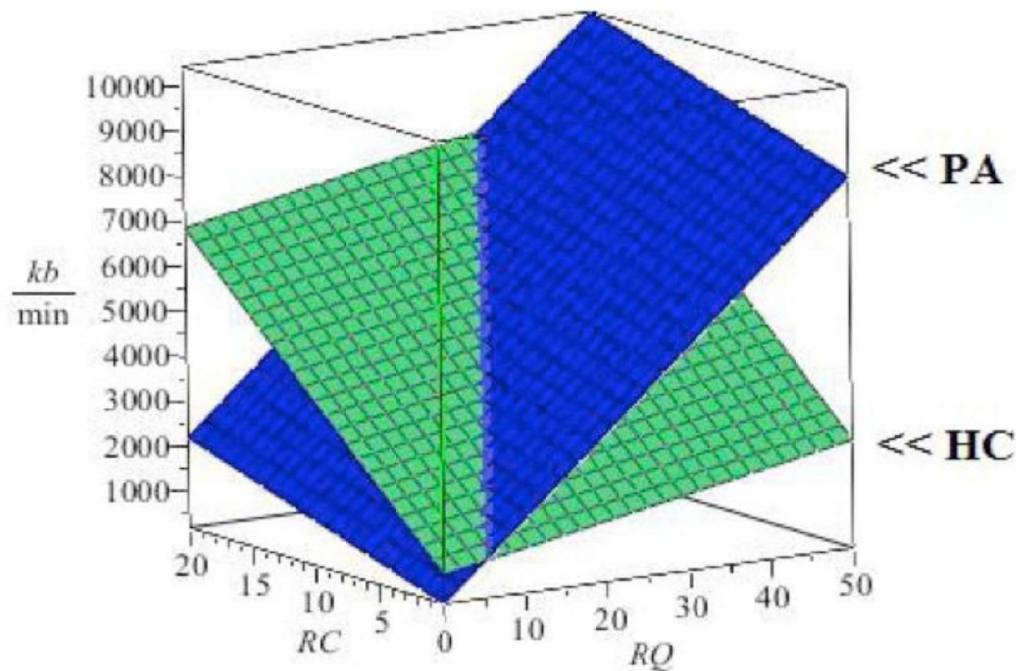
Secure Cloud Storage



Task4 Investigators: Abbe Mowshowitz, Akira Kawaguchi (CCNY); Masato Tsuru, Shibata Masahiro (Kyutech)

RESEARCH APPROACH AND RESULTS

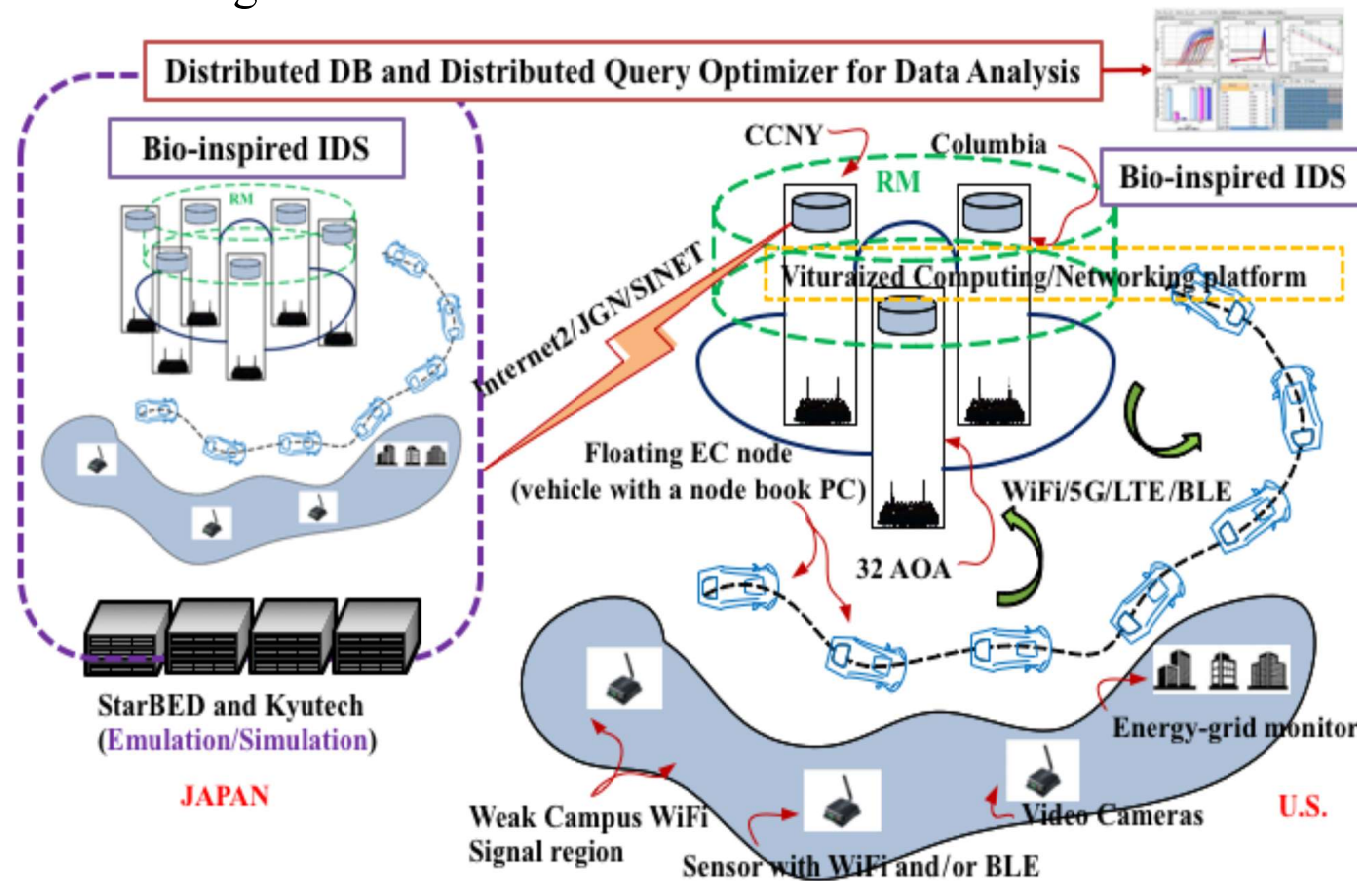
- **Challenges:** 1) maximize use of edge nodes, 2) minimize message traffic, 3) support efficient data querying
- **Approach:** optimize distributed data queries based on network distance between edge nodes



PA: Preferential Attachment
HC: Hypercube
RQ: Rate of Query
RC: Rate of Change in network

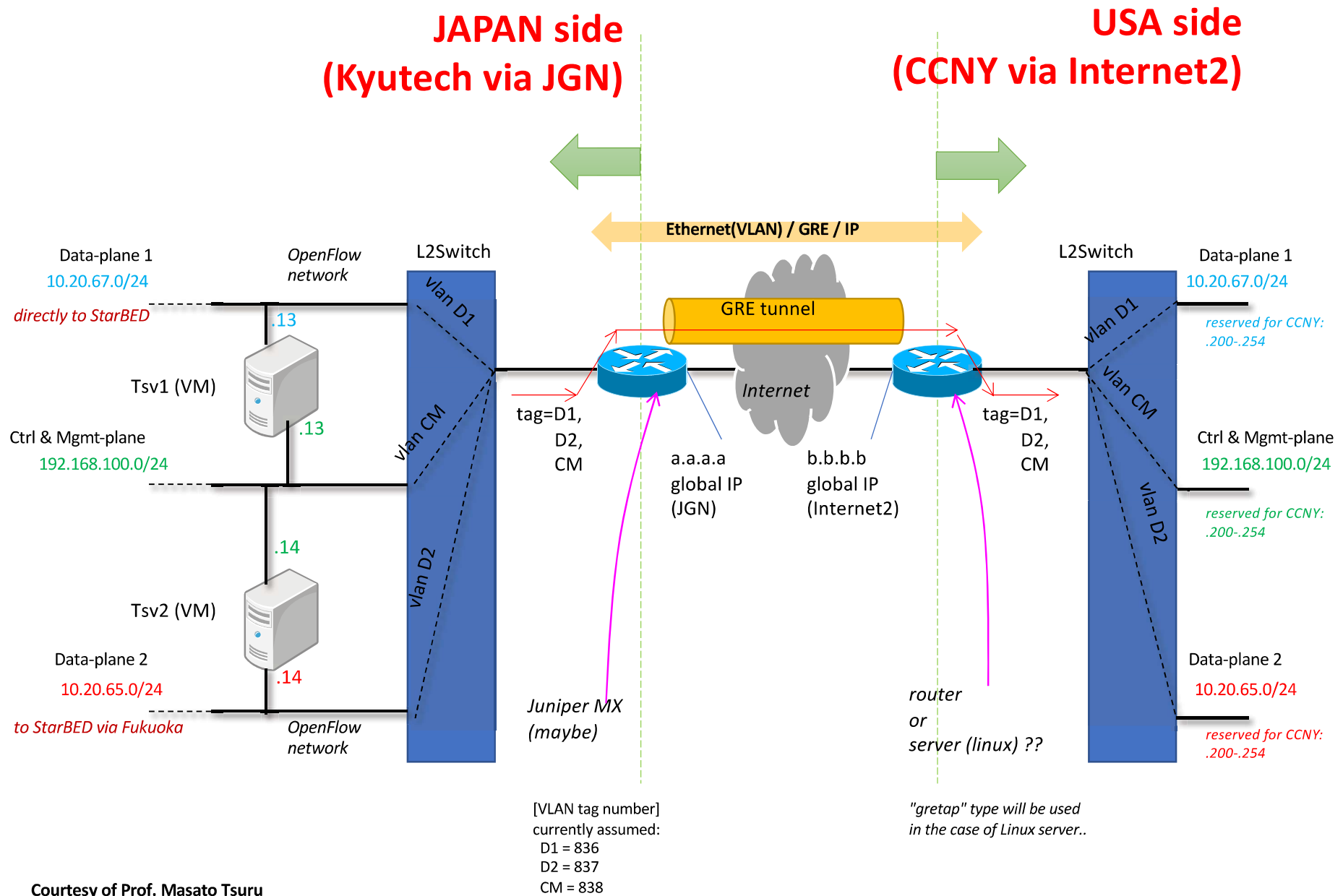
Hypercube advantage:
High RQ, Low RC

- ✓ Integrated Large-Scale Real and Emulation Experimental Testbed across a real city-scale testbed in US (COSMOS) and a large-scale emulation/simulation testbed in JP (StarBED) to realize a global edge-cloud networking testbed with diversity and programmability.
- ✓ Use-case oriented application experiments to evaluate the feasibility and effectiveness, and to clarify the remaining issues.

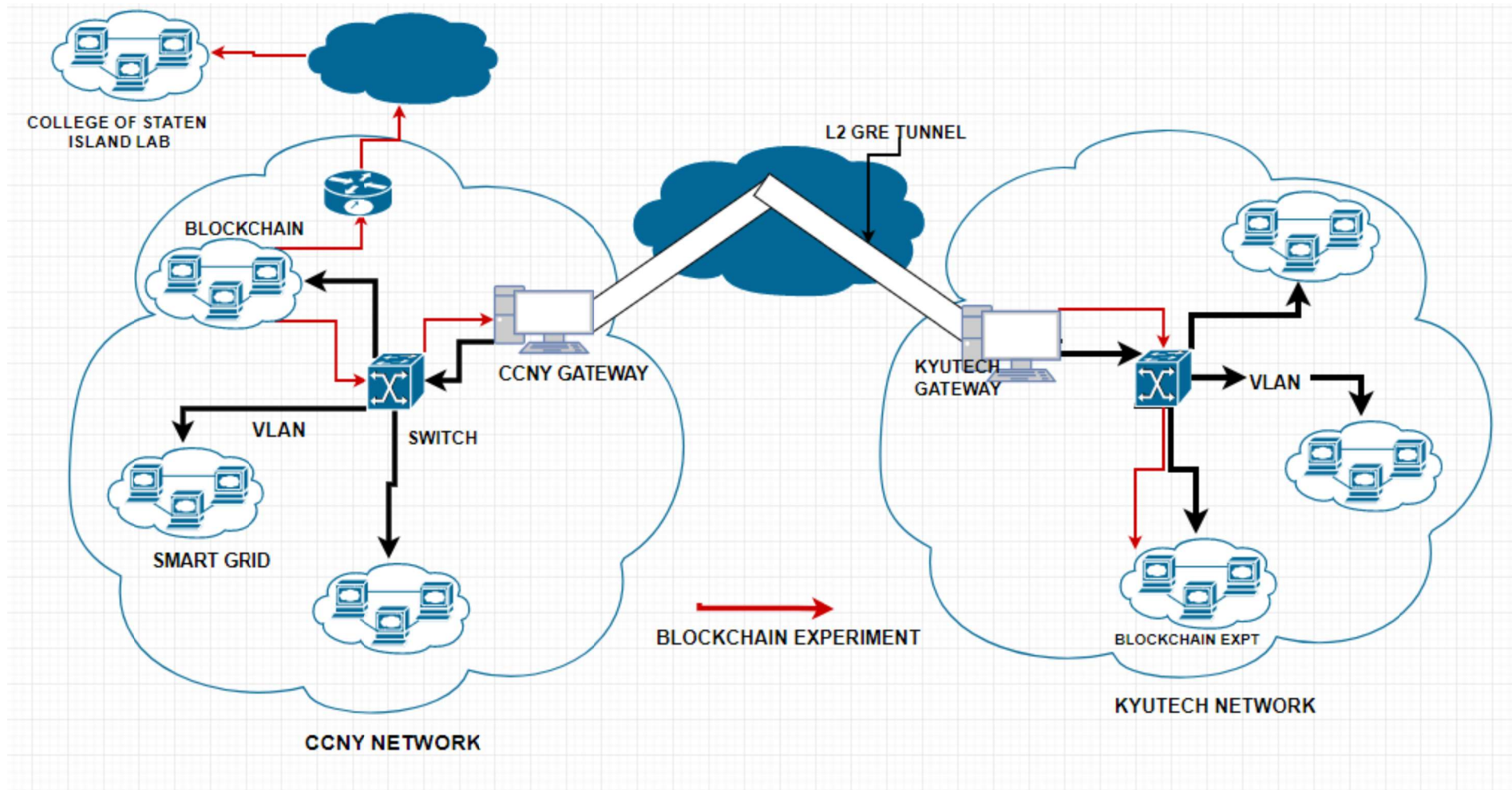


Task Members: Myung Lee and all other members in CCNY; Masato Tsuru and all other members in Kyutech

Network Setup



CCNY-Kyutech Blockchain Collaboration



COSMOS Testbed

- CCNY is the testbed partner of NSF COSMOS (*Cloud Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment*)
 - Currently, both Columbia and CCNY are in the process of installing antennas and fiber network in each campus and interconnect between the two campuses, thus providing for 5G testbed
- Can Kyutech-CCNY testbed be connected to COSMOS testbed?

Thank You

***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)

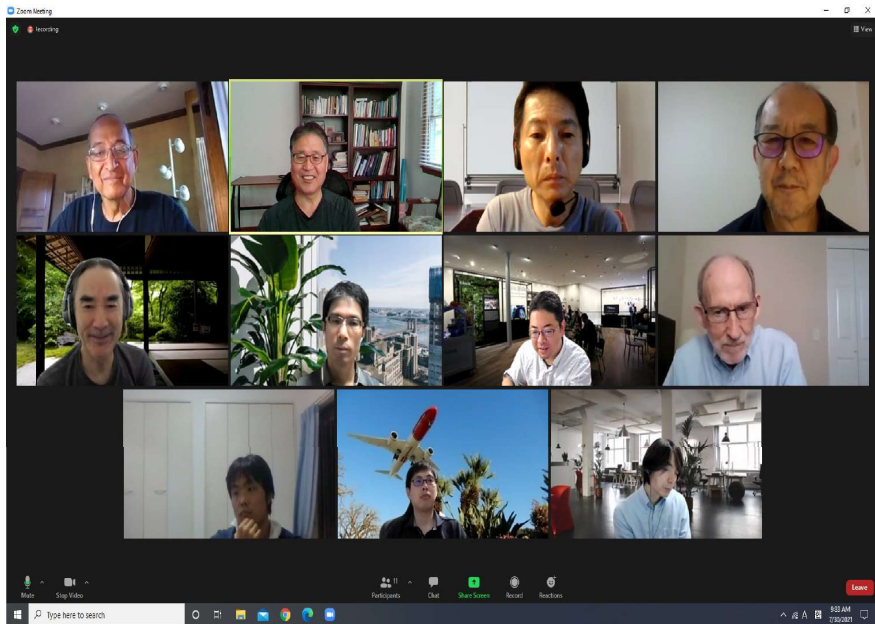
Communications

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)

- **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

- 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

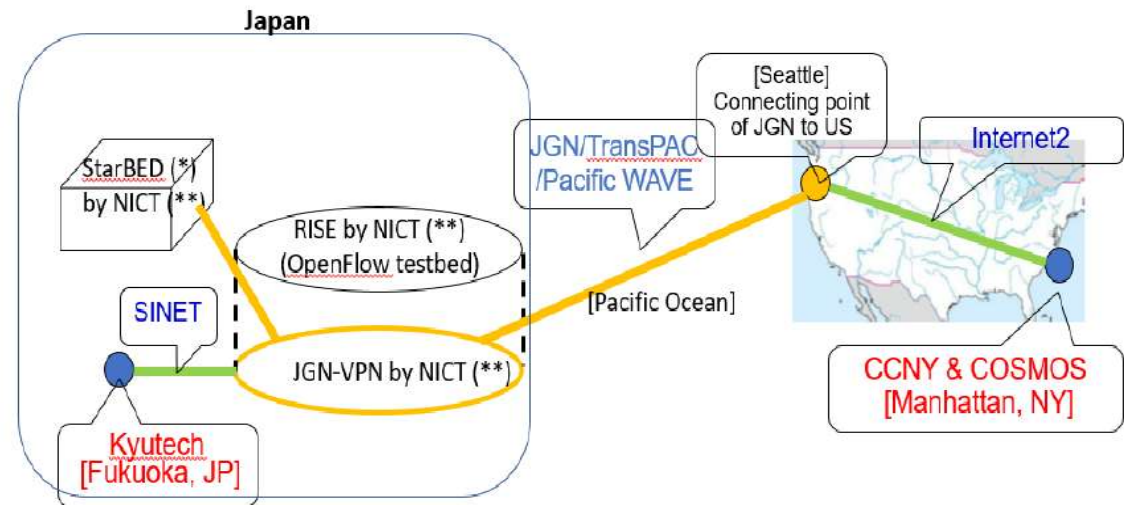
CCNY - Kyutech testbed

✓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.

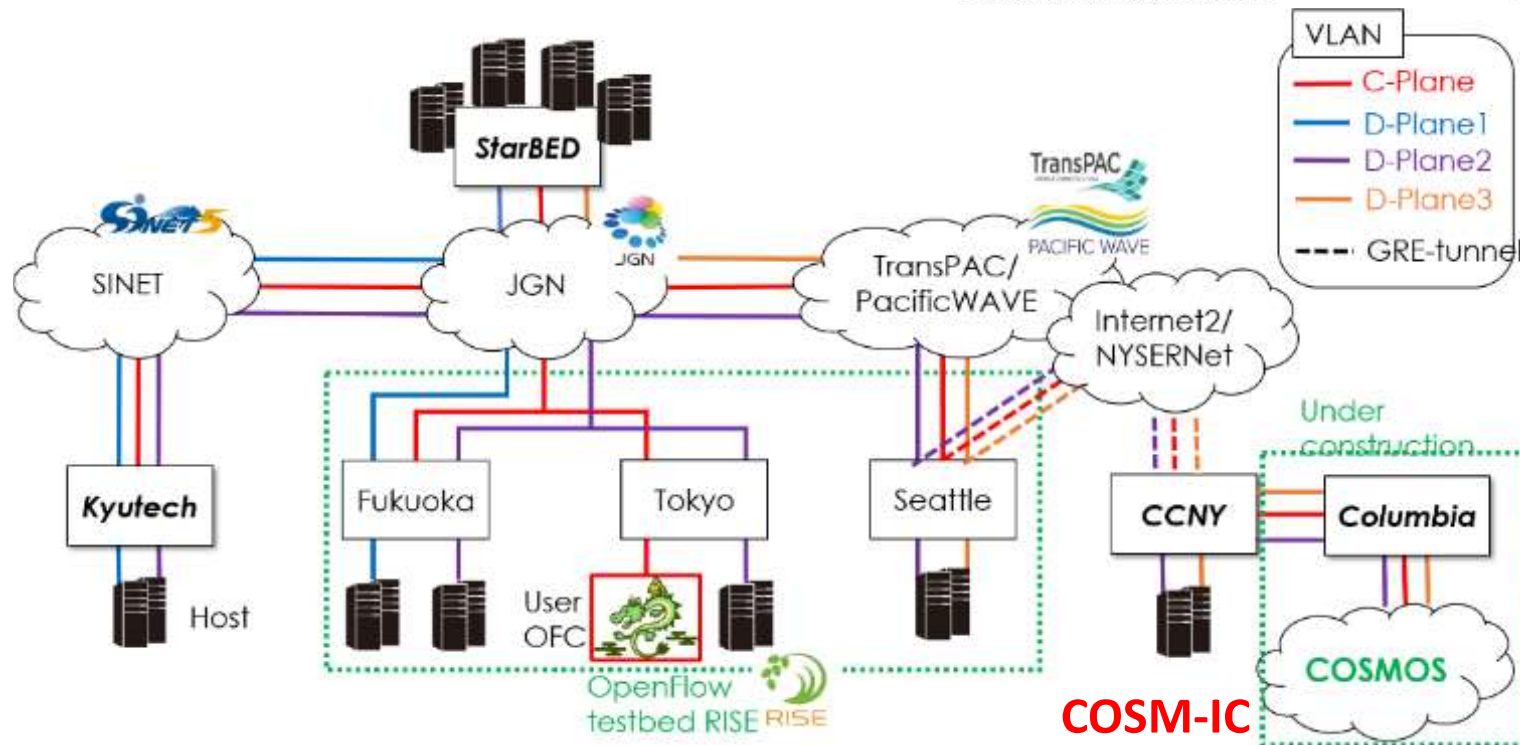
✓**GRE-tunnel** is used to extend VLANs between CCNY and JGN-Seattle.

CCNY-Kyutech, COSMOS Interconnection



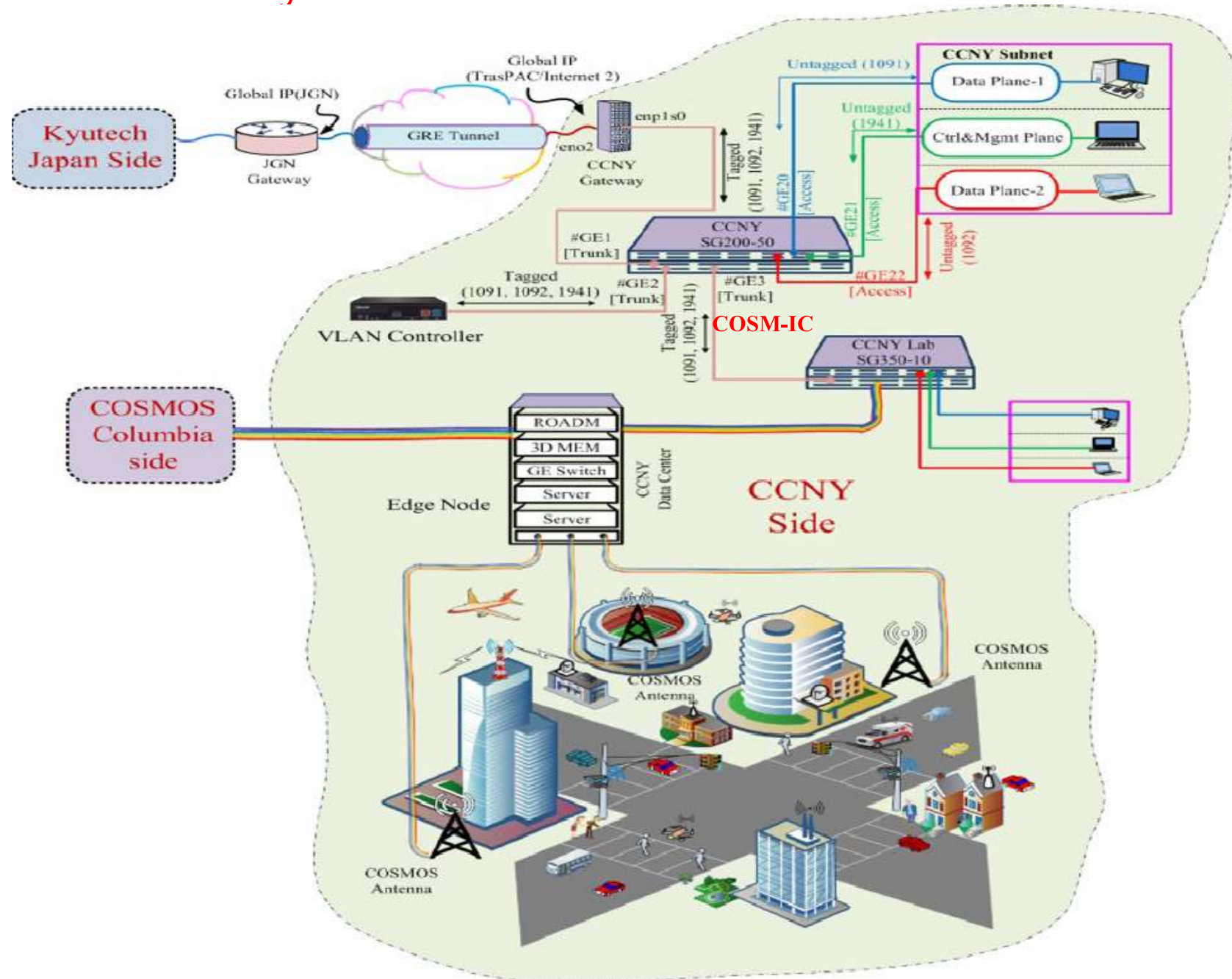
(*) **StarBED**: a large-scale emulation testbed for networking, network applications, information security, and cyber physical systems.

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



COSM-IC

Current CCNY-Kyutech Testbed

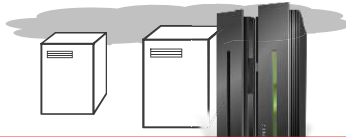


Testbed Future Directions and Real-time International Experimentations

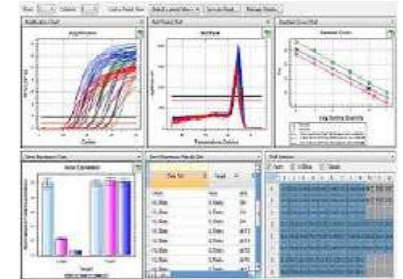
- 1) Working on the fiber installation between **COSMOS node (NAC Bldg)** and the **wireless lab (Eng Bldg)**
- 2) Working on the fiber installation between **the wireless lab (COSMOS access)** and **the cybersecurity Lab (Japan connection)**
- 3) Refining and further testing **CCNY-Kyutech connection (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

Backend-Cloud



Task4: Distributed Database
using Hypercube



Task3: Bio-Inspired Intrusion Detection
System (BIOIDS) for Protecting Internet of
Things Devices

Virtual Network

Task2: Virtualized Adaptable
Computing and Networking

Edge-Cloud

Task1: Resilient Resource Access
for Massive End Devices

Floating EC node



Various wireless access
(Wi-Fi/5G/LTE/BLE)

■ :Virtual Machine
■ :Resource Manager
■ :Bio-inspired IDS

TE: Testbed Experiments

➤ **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 (Kyutech)**, **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.

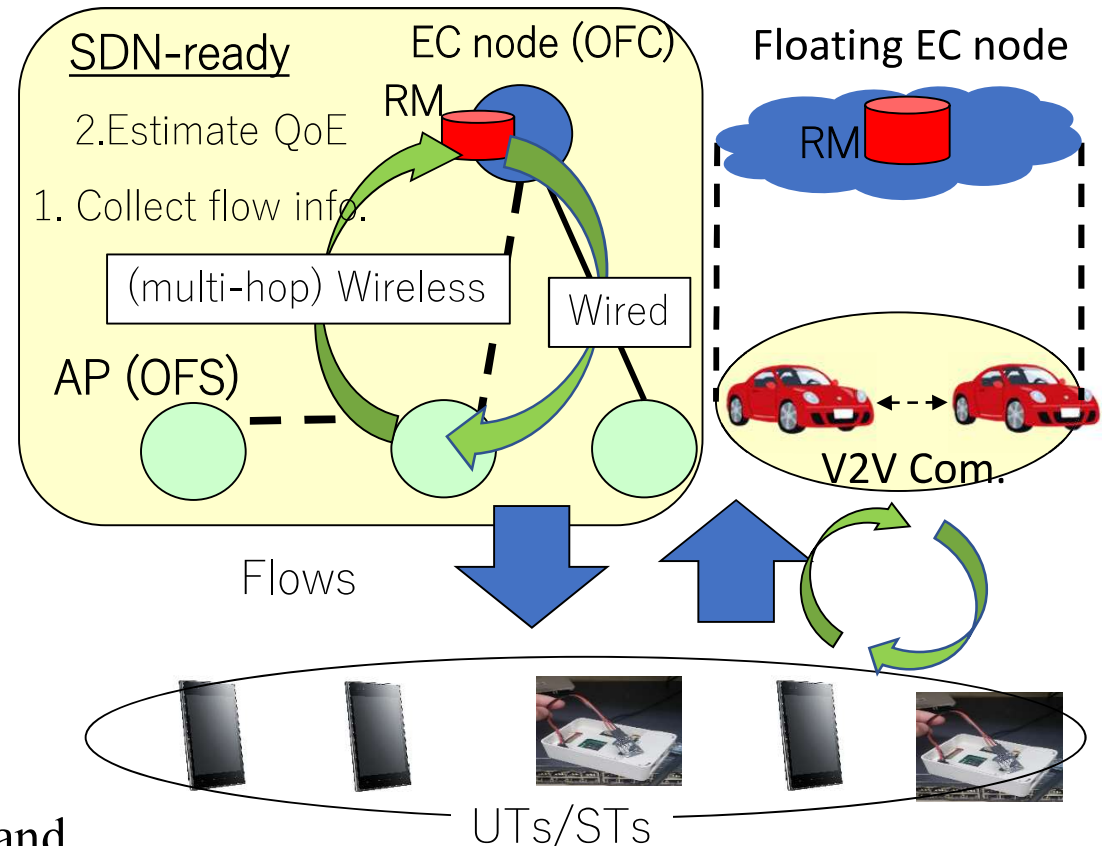


Fig. Concept of End-device networking

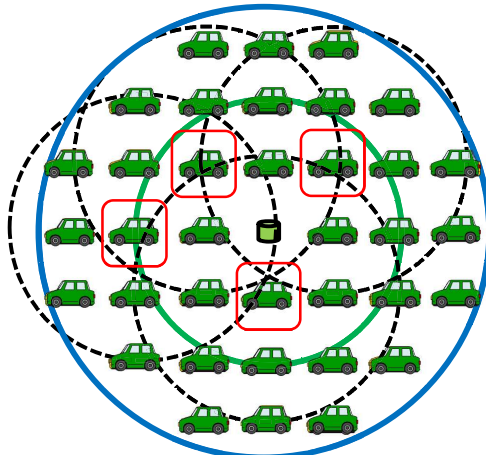
- ✓ In resilient situation:
 3. coverage maintenance/extension by introducing spatio-temporal floating EC nodes

Task Members:

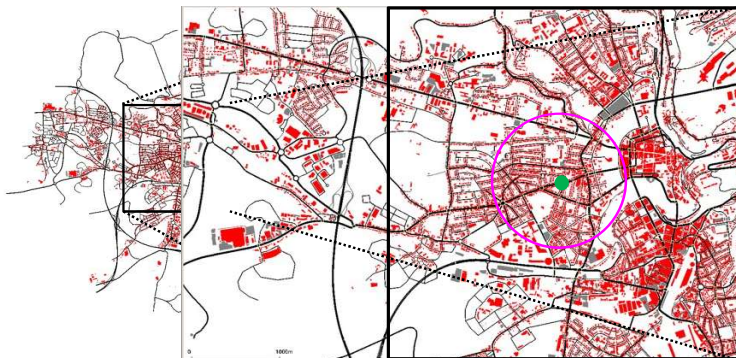
Myung Lee (CCNY); Kazuya Tsukamoto, Takeshi Ikenaga, Daiki Nobayashi (Kyutech)

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

- 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

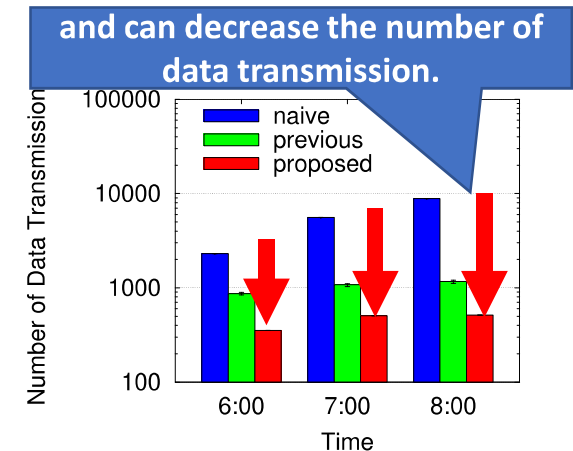
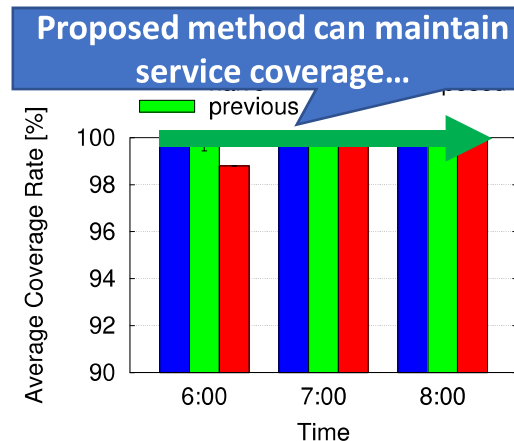


Luxembourg's traffic model

- Experiment

- We evaluate our proposed scheme using **the network simulator Veins (OMNeT++ and SUMO) and realistic traffic model of Luxembourg (LuST)**.
- 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



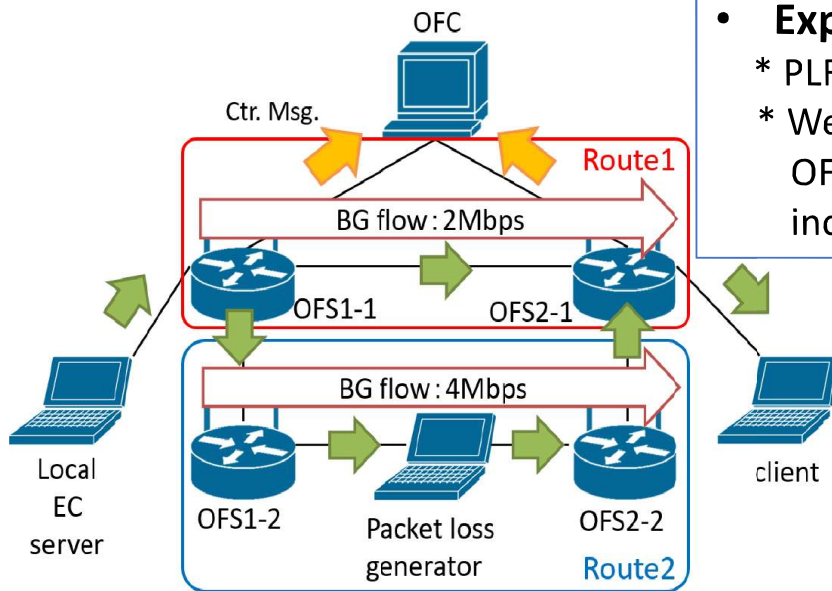
Simulation Results using Luxembourg's traffic model

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

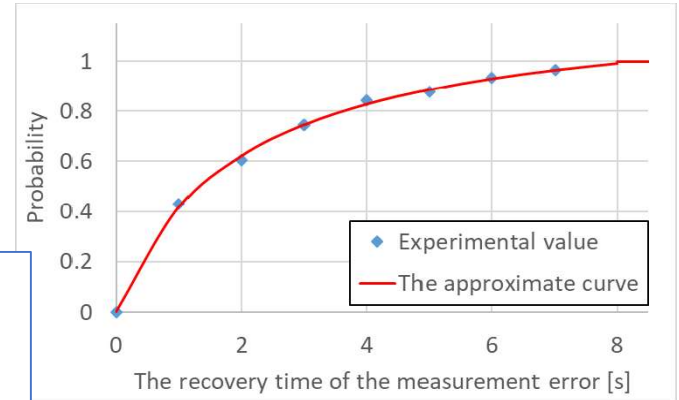
- To achieve resilient communication via flow-based control, we propose the following three functions.
 - An Identification method for new arrival flow using OpenFlow control messages
 - RTP flow can be identified correctly based on ML by using first 15 consecutive **pkt_ins**
 - SDN-based in-network two-staged video QoE estimation method
 - 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**
 - Route selection method by exploiting functions of 1. and 2.

Experiments

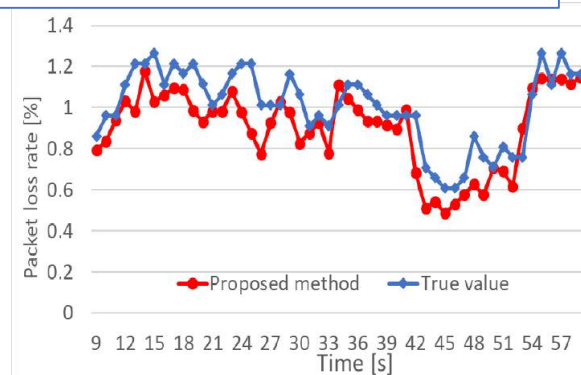
- * PLR is set to 1% (severe condition)
- * We measure in-network (at the OFC) estimated QoE of the incoming RTP flow (G.1071)



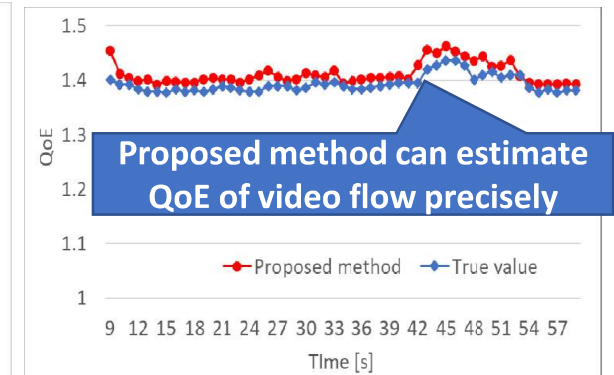
Network topology for experiment



CDF of the meas. err. recovery time



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!

- 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

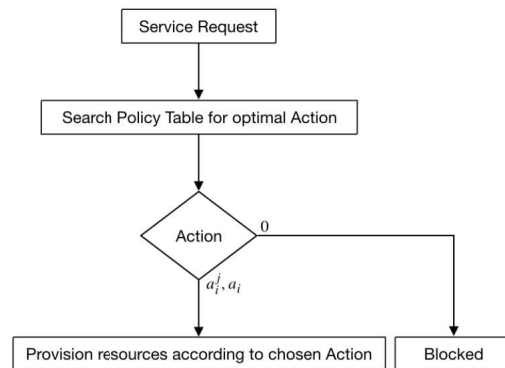
- Columns represent the occurrences of the states of the system
- Rows represent probabilities of actions taken by the system in their corresponding states (columns)

2. Index-based search technique over structured policy table

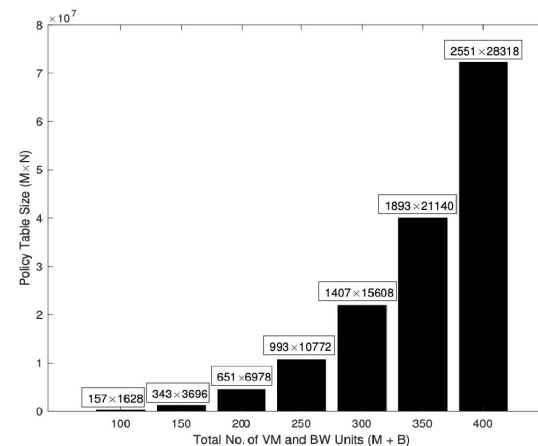
- The indices of the states, actions and max occurrences of the states are stored as $1 \times N$ vectors
- System has information about the current state (column), therefore, rest of the columns are eliminated during the search
- RM decides actions depending on the probabilities

	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_2^1	0.53	0.20	0.16	0.20		0.45	0.30	0.30	0.18
a_3^1	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
	x_1^2					x_2^1			

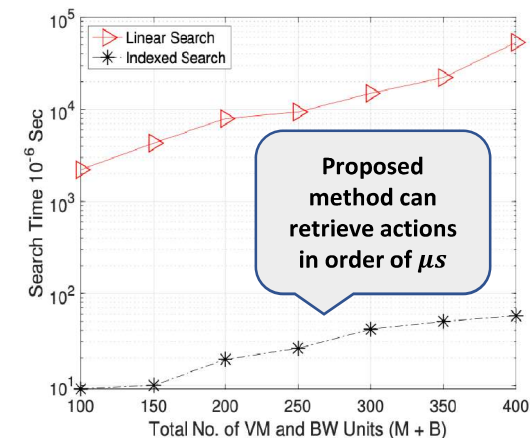
Policy Table for Service Requests



Search-Flow for resource provisioning by RM



Exponential growth in PT: ~72 Million



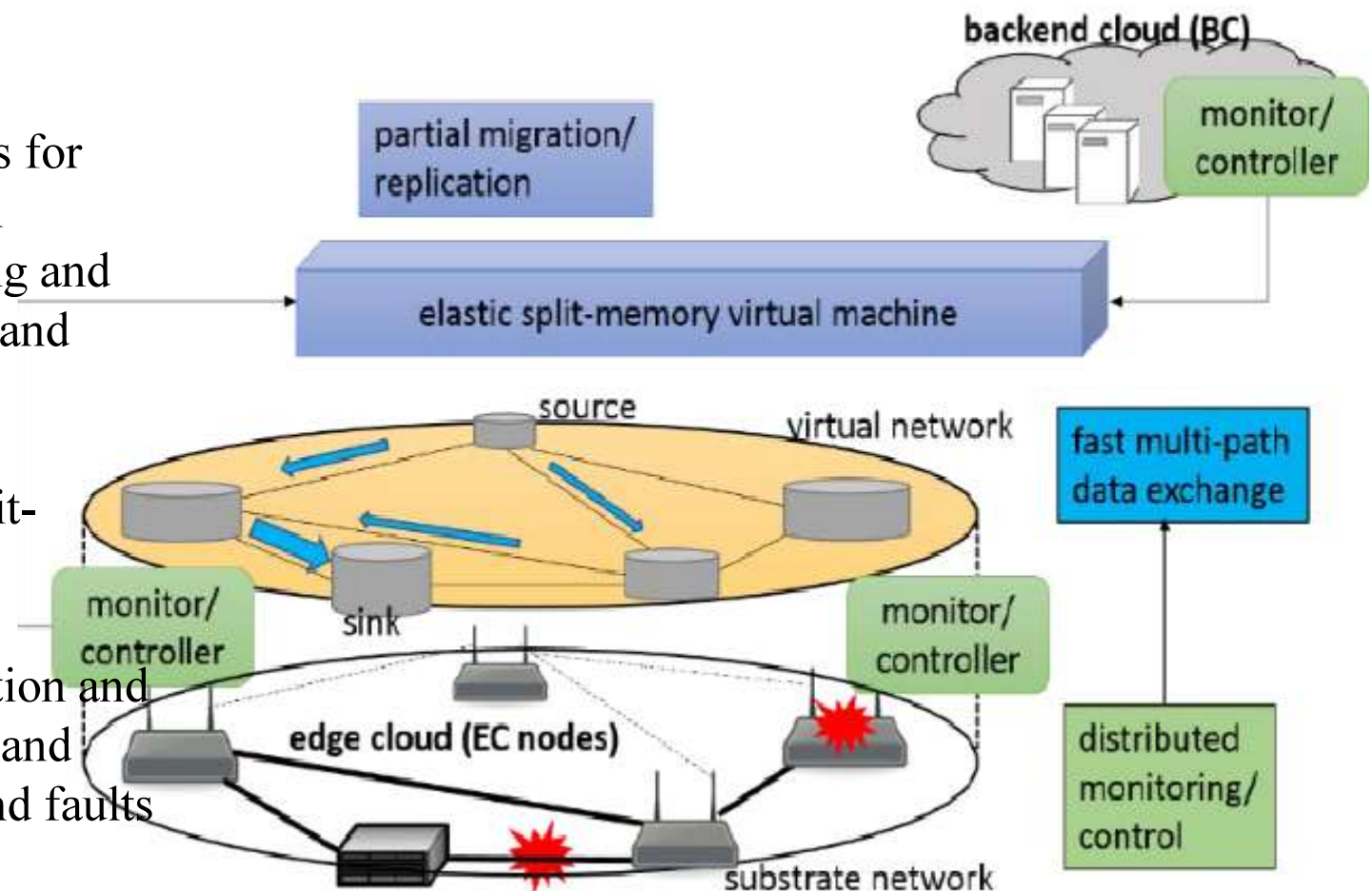
Search time comparison

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)

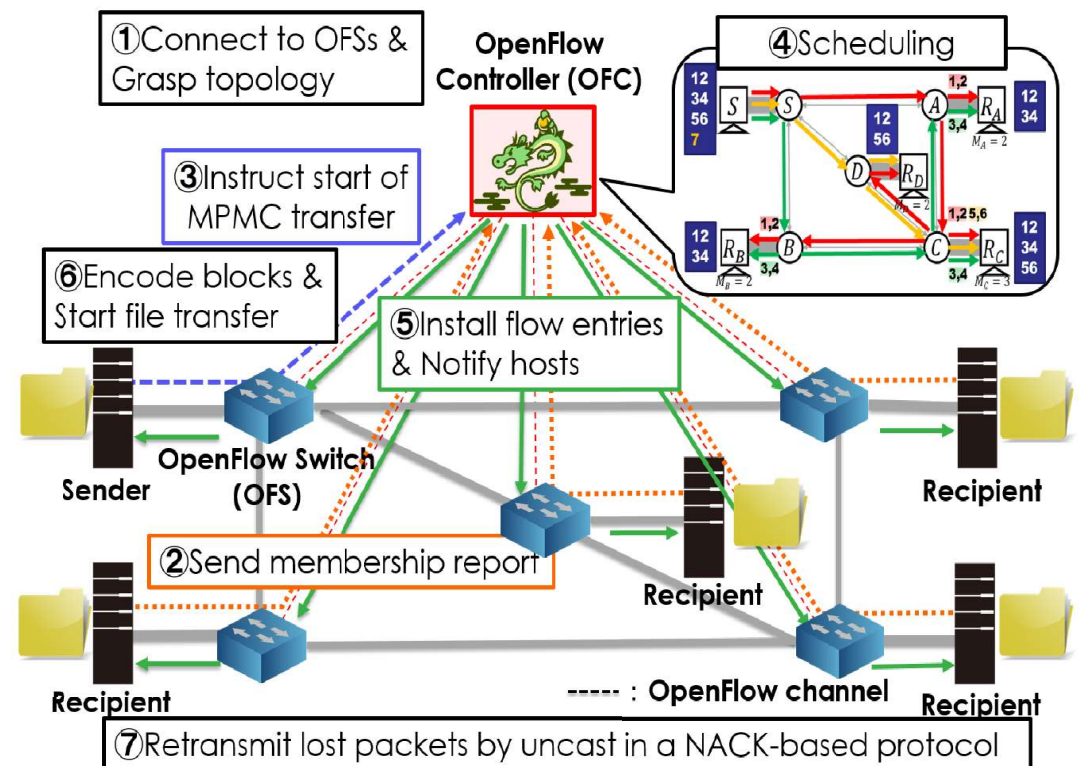
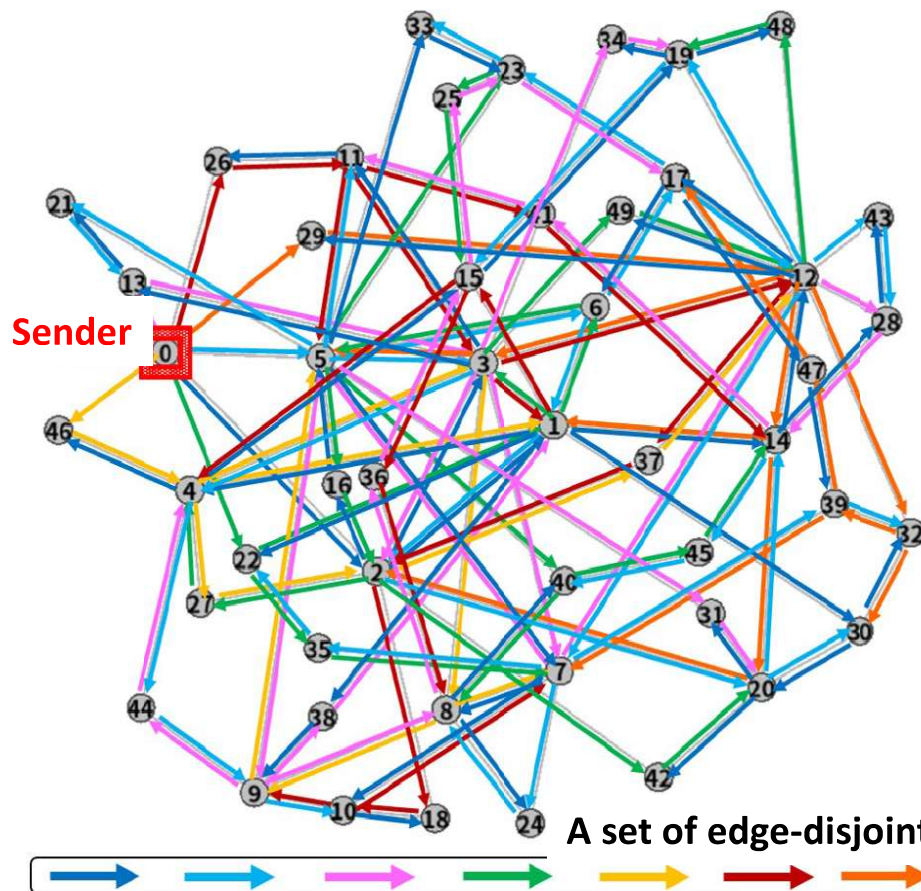
T2.1: Fast multi-path data exchange

✓ **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.

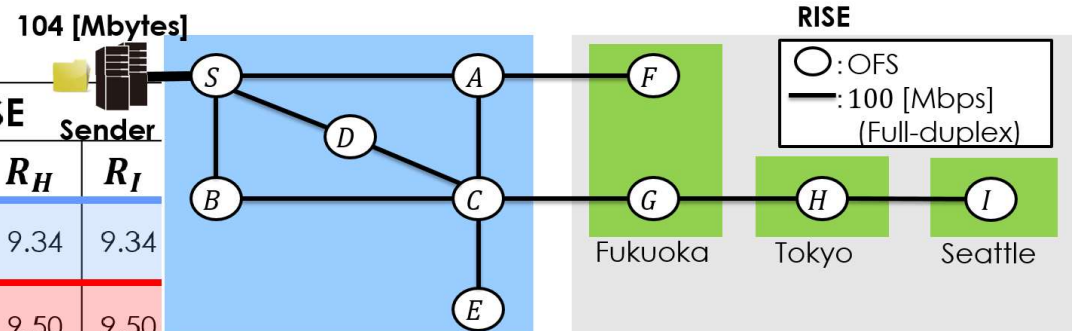
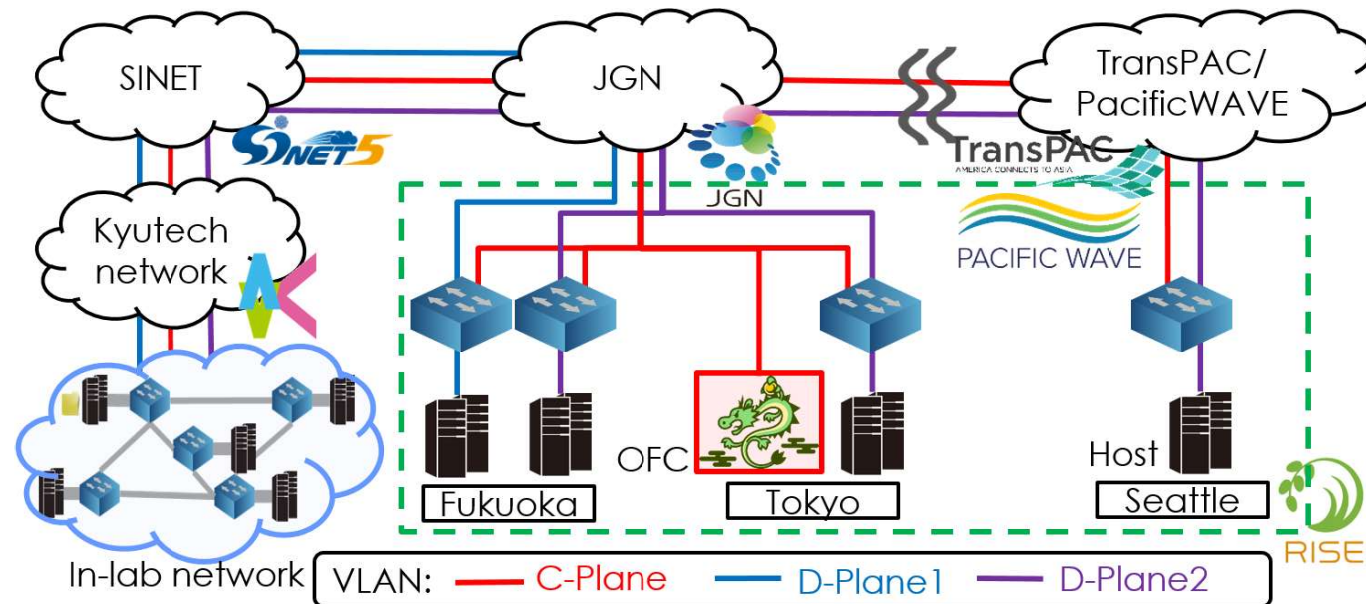
✓ OpenFlow (OF)-based prototype implementation: Evaluation on Mininet, InLab-OF network, and the US-JP testbed.



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				Sender
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	

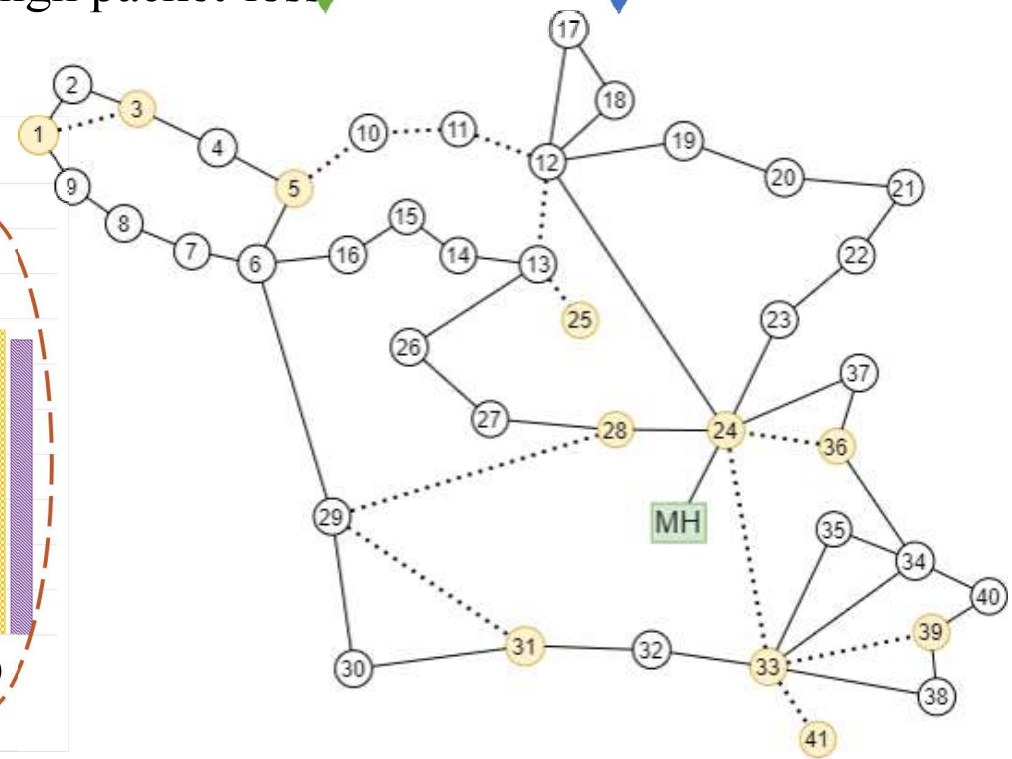
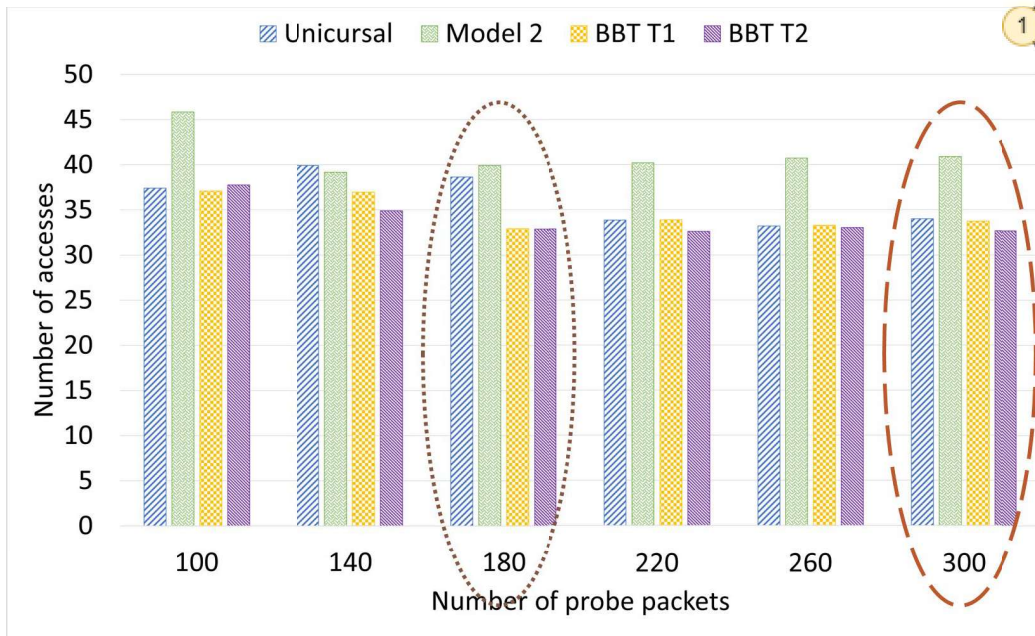
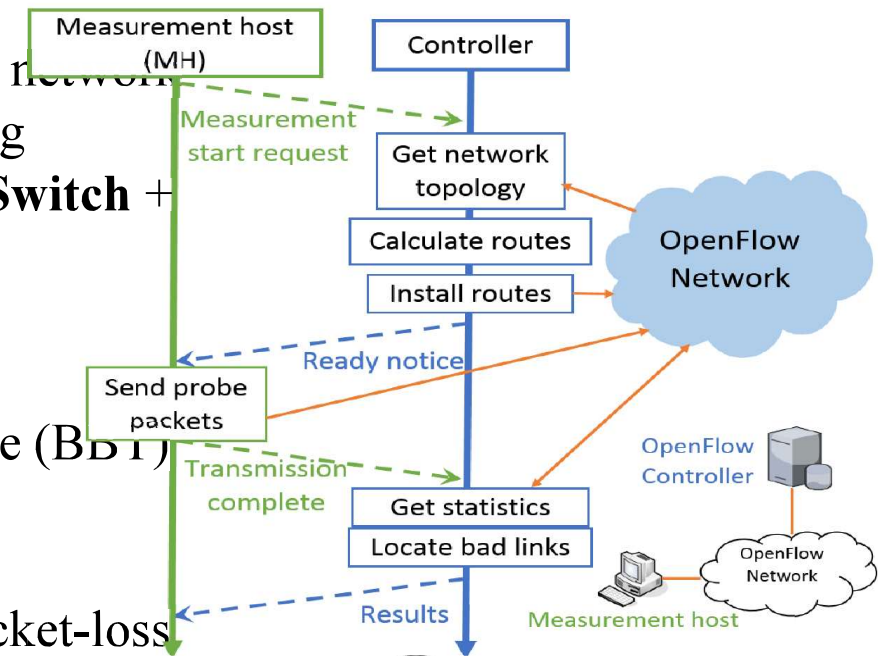
T2.2: Distributed monitoring of network links

✓ Network-Assisted Monitoring Framework:

Detection/location of bad links on OpenFlow (OF) network by (1) Packet probing 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.**

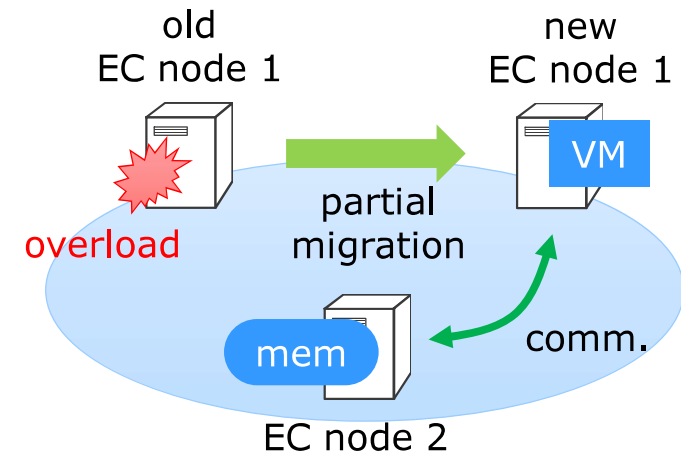
- ✓ By Euler circle-based design of multicast route (BBT) and Network tomographic access ordering for monitored results collection.
- ✓ Simulation & Mininet Emulation: for high packet-loss and high packet-delay-variance.



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

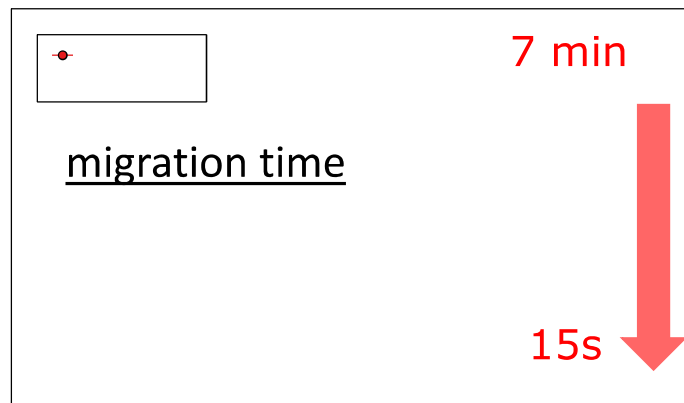


- Optimization of network communication for split-memory VMs

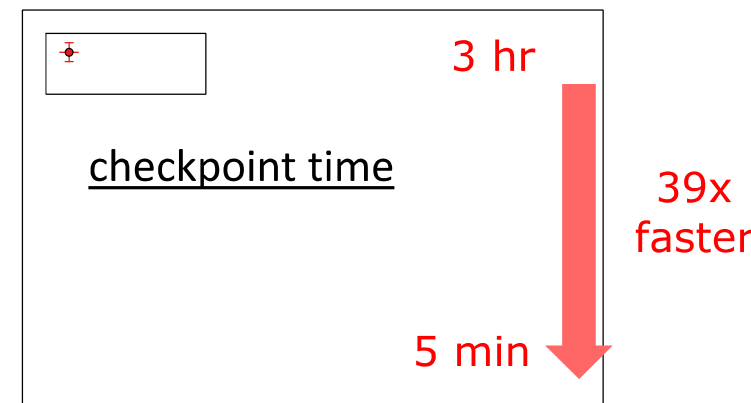
- Avoid transferring the data of unused memory in a VM (left figure)
- Transparently identify memory regions that are not used by the system in a VM

- 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



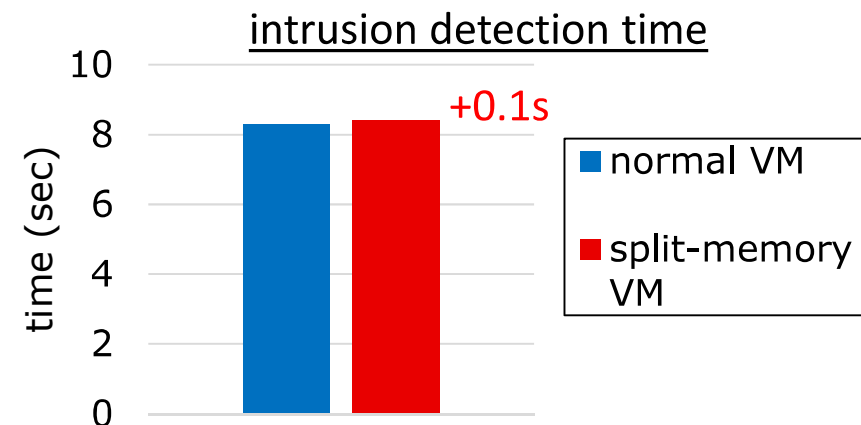
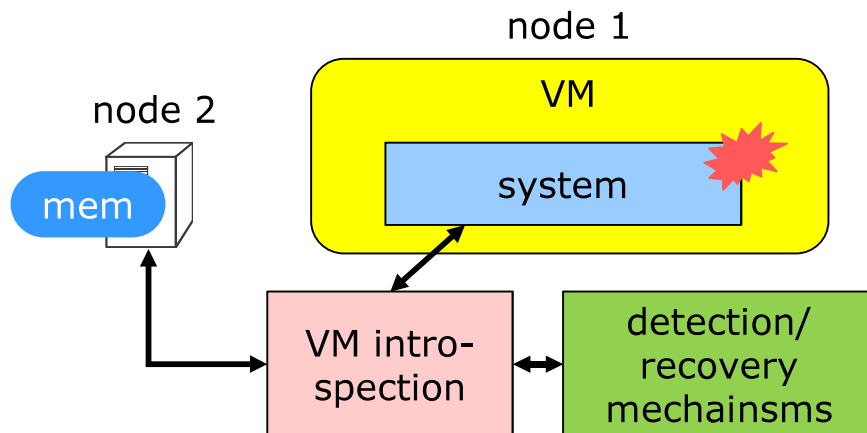
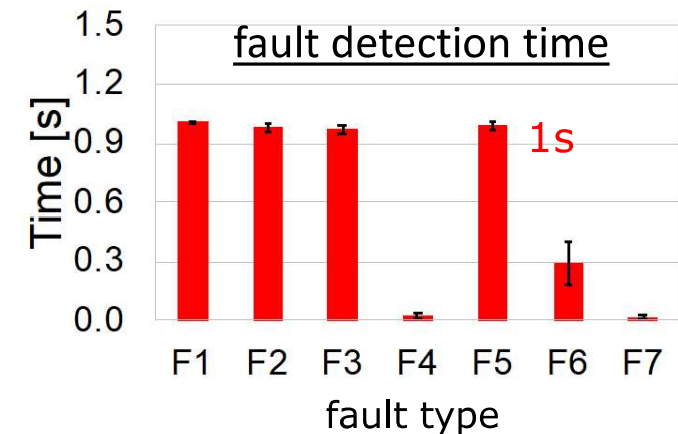
29x
faster



39x
faster

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



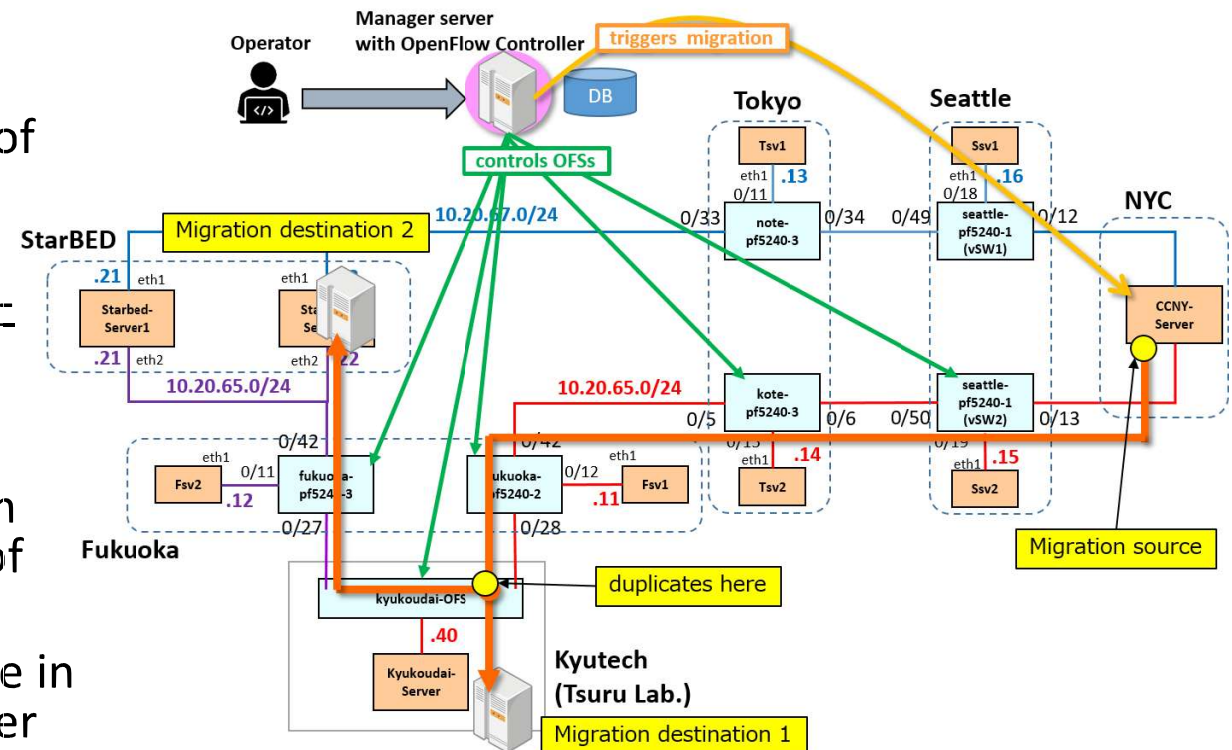
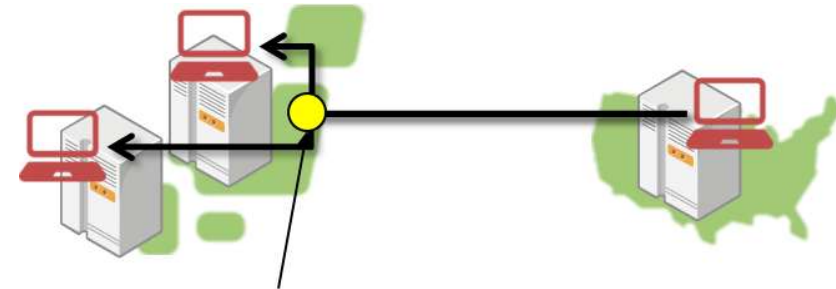
Testbed Experiment (Task2)

- **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).



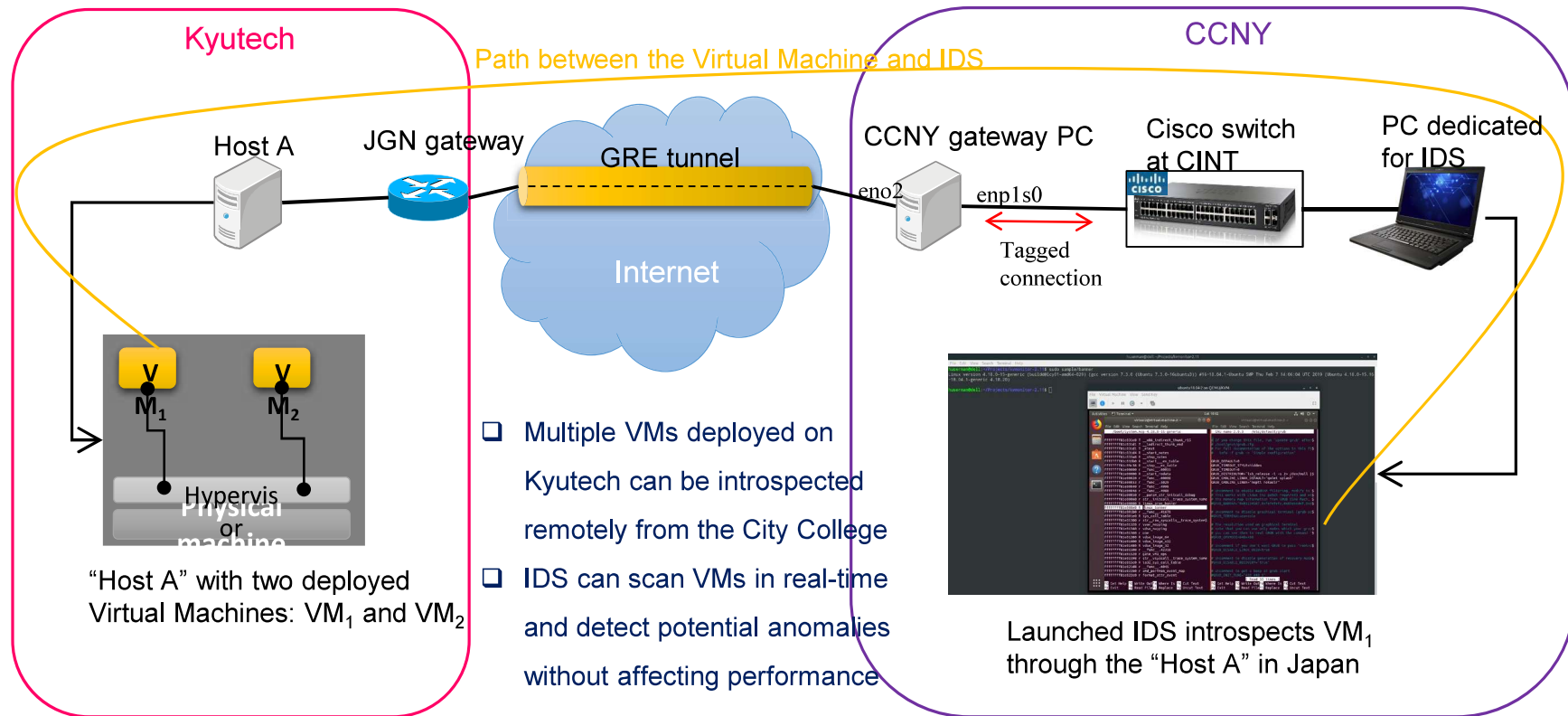
Task 3 Secure VM Introspection

International Realtime Testbed Experiment

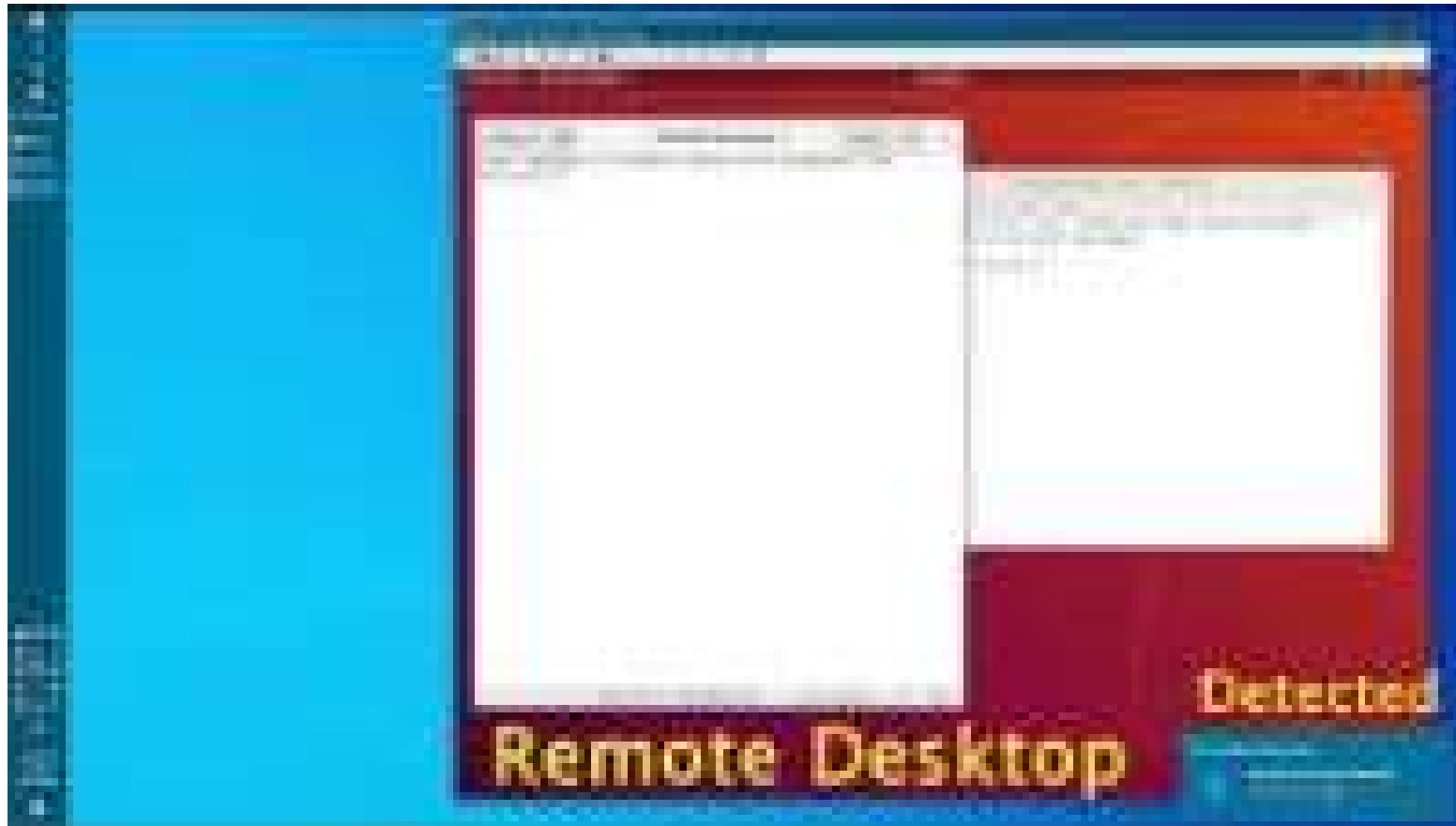
Scenario: A Japanese business person makes an overseas trip to US; Access his/her VM running in Japan from US, Use remote desktop (VNC) in his/her laptop PC, Monitor attacks against the VM by running BioIDS in his/her laptop PC

The City College
of New York

Kyutech
Kyushu Institute of Technology

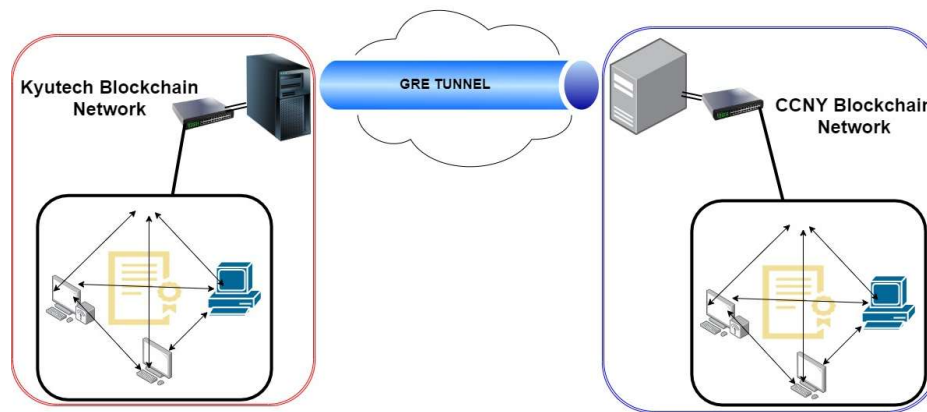


Task Members: Tarek Saadawi (CCNY); Kenichi Kourai (Kyutech)

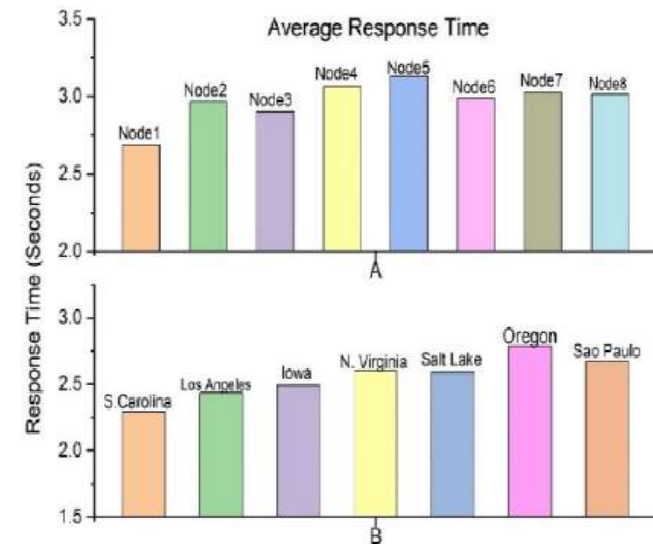


- DEMO
- Applied for joint patent (CCNY and Kutech)

2) Interdomain Blockchain Co-IPS Experiment



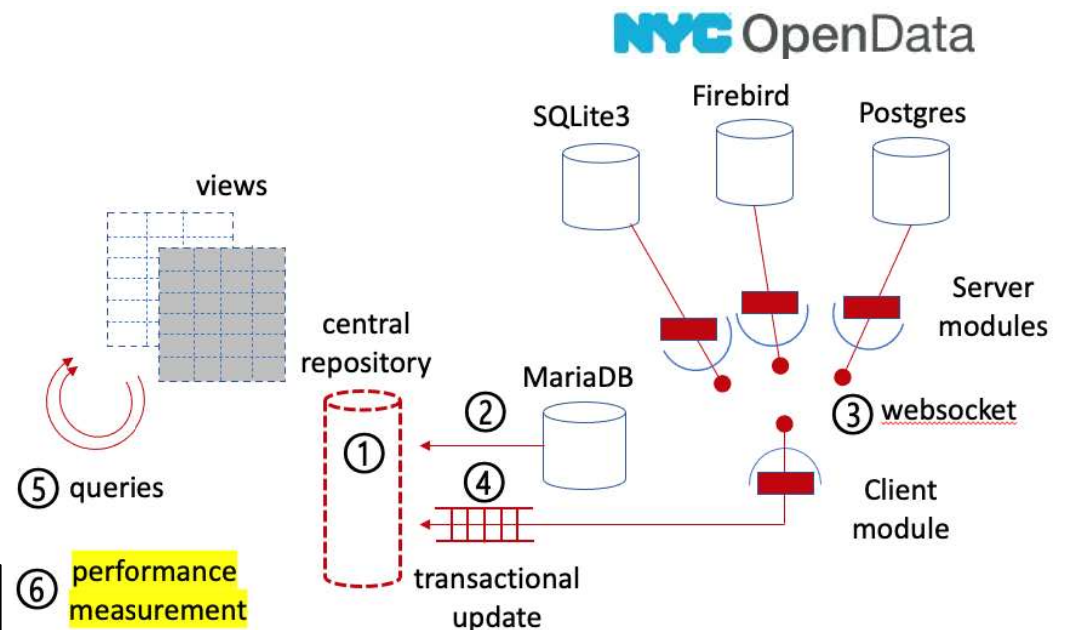
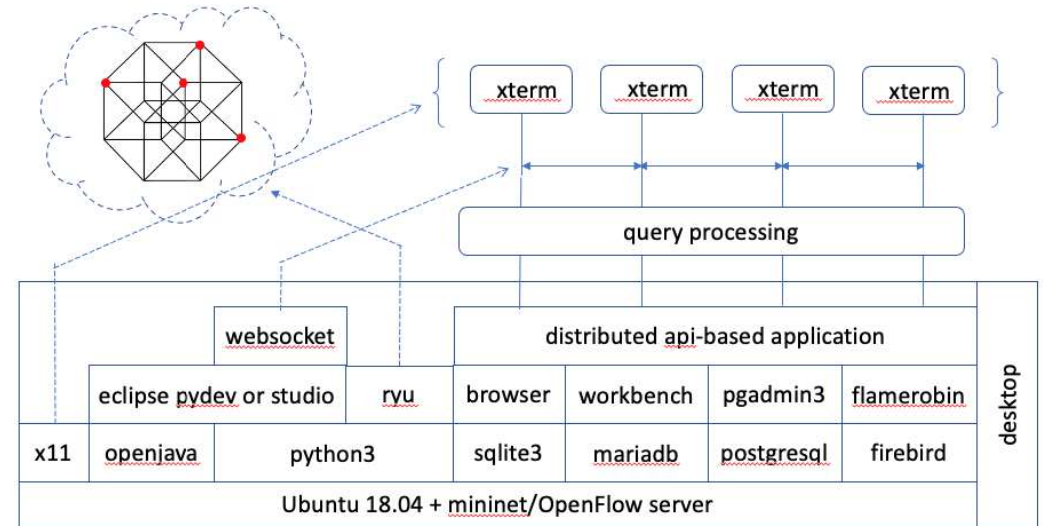
- Ran an Interdomain real-time experiment for co-operative intrusion detection system (Co-IDS)
- Initial results show the average response time of each node (time for other nodes receives the attack signature) to lie between 2.5 to 3.0 seconds



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)

Task 4: Dynamic Systems Modeling (2/2)

Other Overlay Topologies

- Toroidal grid graph
- Kautz graph

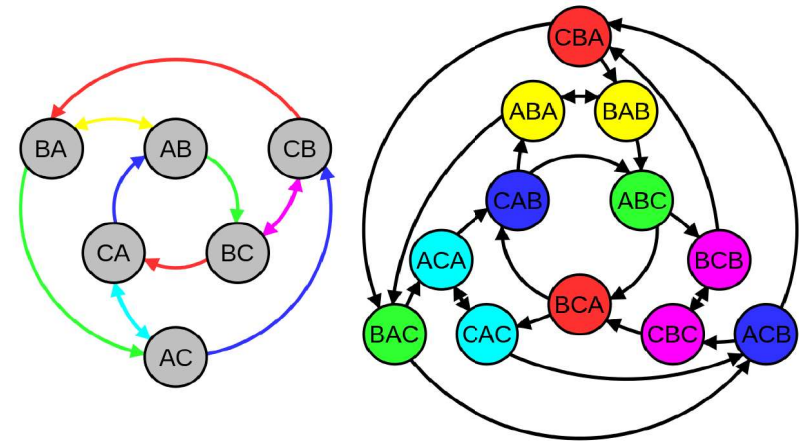
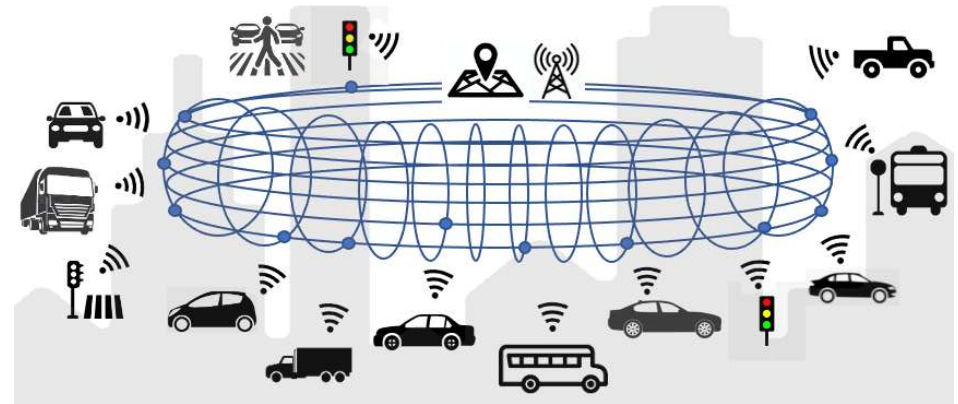
Desirable Properties

- 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