Next Generation Cybrer Infrastructure

Democratizing 6G Research

Aki Nakao

Professor, School of Engineering, The University of Tokyo

Chair of XGMF (XG Promotion Forum)

Special Advisor to the President of The University of Tokyo

Director of Collaborative Research Organization for Next-Generation Cyber Infrastructure, The University of Tokyo

Aki Nakao

- Professor, Department Head of Systems Innovation, School of Engineering, the University of Tokyo
- Special Advisor to the President of the University of Tokyo
- Director of Next Generation Cyber Infrastructure Institute, the University of Tokyo

- Member of Science Council of Japan
- Co-Chairman of XGMF
- Chairman of 5G/Beyond5G Committee of Space ICT Forum
- Community Informatization Adviser to the Ministry of Internal Affairs and Communications, Japanese Government
- Chairman of Local5G Promotion Research Group
- Founder of FLARE SYSTEMS

XGMF Launched

5G Mobile Communications Promotion Forum (5GMF)

Beyond 5G Promotion Consortium (B5GPC)

Consolidated

From April 2024

XG Mobile Promotion Forum (XGMF)

https://xgmf.jp/en/

Co-chair
Prof. MORIKAWA, Hiroyuki (UNIVERSITY OF TOKYO)
Prof. NAKAO, Akihiro (UNIVERSITY OF TOKYO)

Number of members: 129 (as of August 26, 2024)

B5G Campus Testbed Concept

The strategy is to implement new ideas in society as quickly as possible and get feedback as quickly as possible.

- Testbed for democtratizing B5G network technologies
- Verification of social acceptability of technology
- Human resource development and industry-academia human resource circulation
- Promote interactive international collaboration to attract outstanding human resources

Closed Competitive Domains

Company A	Company B	Company C	National Laboratory D	Foreign University	Foreign Research Lab	Standardization Body

Open Cooperative Domain

B5G Campus Testbed Concept for Rapid Deployability First

NGCI: Collaborative Research Organization for Next-Generation Cyber Infrastructure

DevShowcase@NakaoLab

NAKAO LAB

- Showcase for Industry-Academia collaboration
- For PBL education
- Local5G (Sub6-SA) License Obtained

Project Based Learning Using Local 5G (Licensed) Environment

Industry Collaboration Activities at “DevShowcase”

NAKAO LAB

Bsuiness Finland
6G Local Public Networks seminar
（2023/5/8）

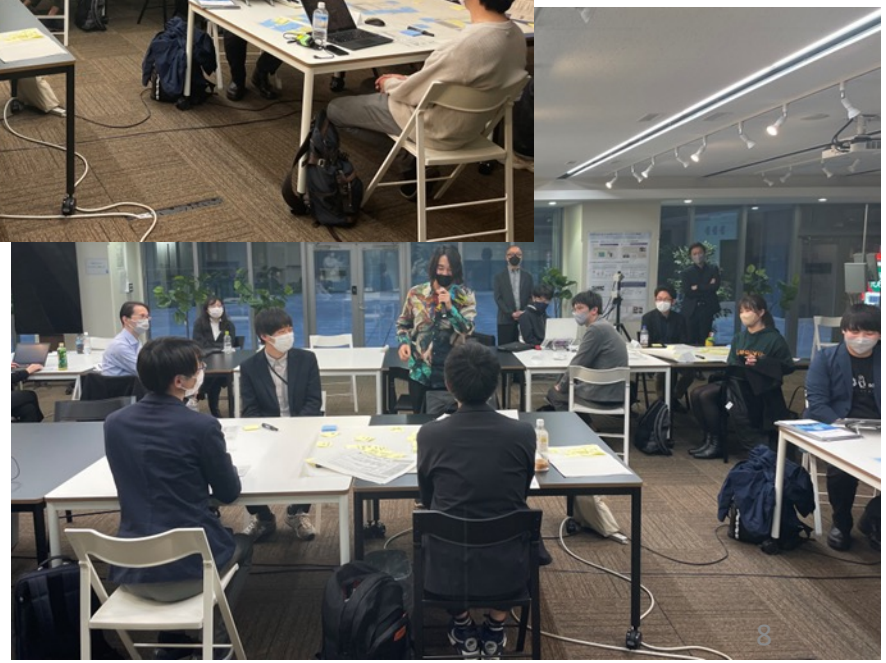
Local 5G Promotion Working Group
The 2nd Local 5G Interoperability Plug-Fest
（2023/4/27）

Industry Collaboration Activities at “DevShowcase”

NAKAO LAB

NEC Internship （2023/8/28-）

NEC Social Collaborations Workshop （2023/3/30）



Local 5G

- Local 5G enables the following:
  - ☐ **Establishment of customized networks with flexible specifications** that meet local needs
  - ☐ **Establishment of 5G systems prior to area coverage by mobile carriers**
  - ☐ **Operation of networks less vulnerable to communication failures and disasters**.

Use cases of Local 5G

Connected terminal

Tele-medicine

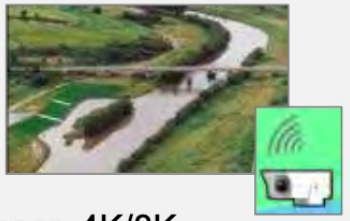
4K/8K movie

Smart construction

Smart factory

Remote work

River monitoring

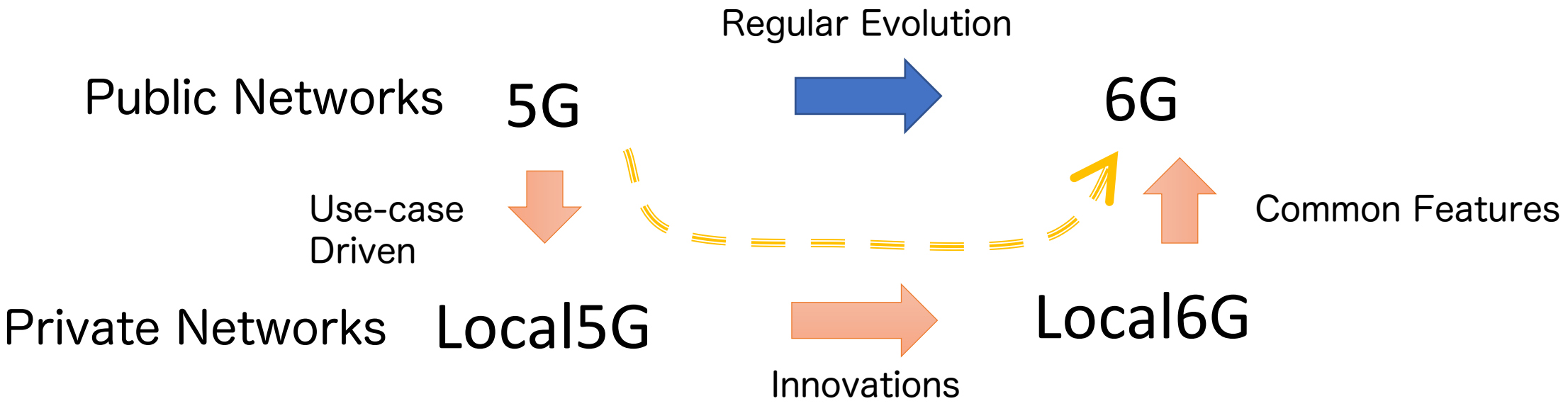


Sensor, 4K/8K

Farming automation

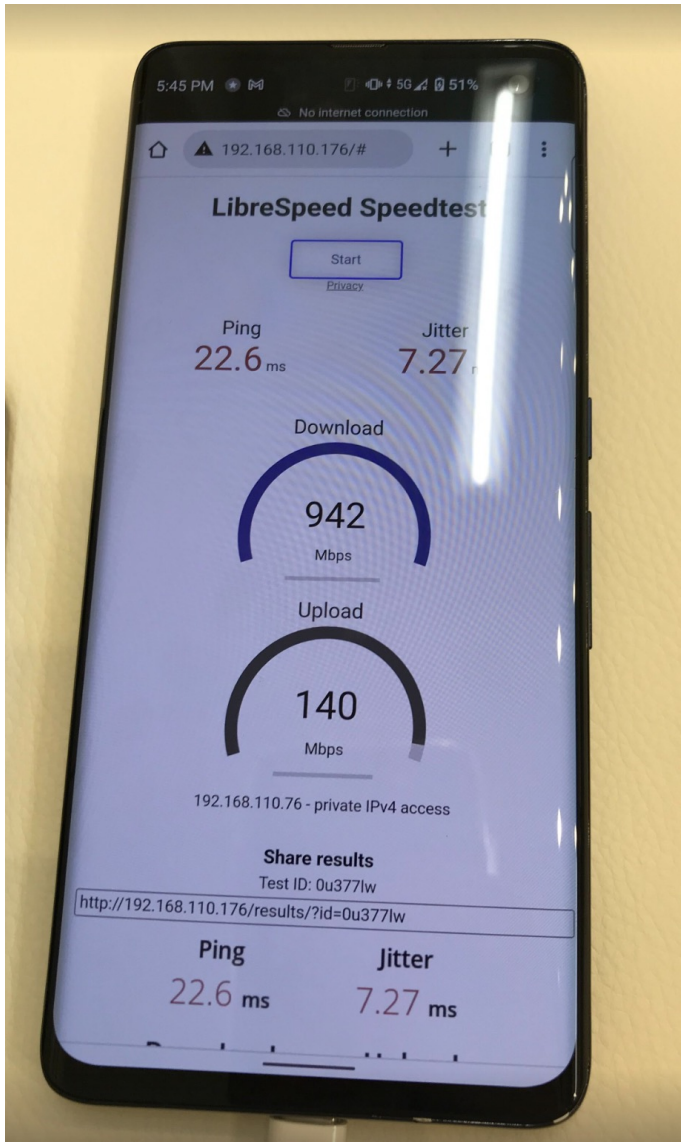
Slide provided by Ministry of Internal Affairs and Communications, Japan

Democratization:
6G will be driven bottom-up from Local6G / Private 6G



Various Innovations driven by “customizations”

Softwarized Portable Local 5G Box



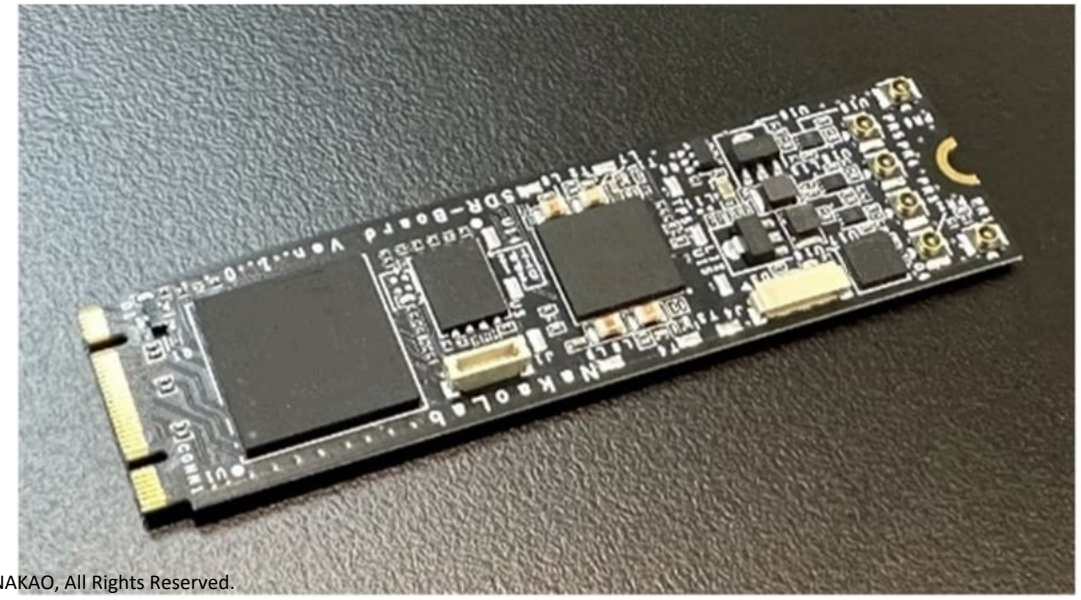
2023/3/24 Press Released

Ultra-compact Software Defined Radio Board

- Accelerating Development of Programmable Base Stations Evolving with Software Expansion -

NICT B5G Fund Project “Research and Development of B5G IoT SoC and IoT solution Building Platform of Continuous Evolution”
Grant #00801

- We have successfully developed an “ultra-compact” software-defined radio (SDR) board that supports the development of next-generation communication standards .
- We have developed a board that supports M.2 standard interface, ultra-compact size (80mm long, 22mm wide , 5mm thick (board thickness 0.8mm)) and can be programmed with 5G and next-generation communication protocols.
- We will accelerate the resolution of social issues, the exploration of latent needs, and the creation of value through confirmation and verification of usefulness in demonstrations using 5G/B5G communication equipment that utilizes SDR.



- ultra-compact: Compatible with M.2 standard.
- Height 80 mm, width 22 mm, thickness approx. 5 mm
- Flexibly add network functions through software
- Expand frequency bandwidth by daisy chaining multiple boards
- Confirmed to work as a 5G base station

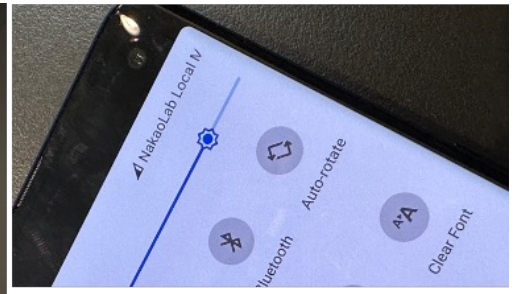
NAKAO LAB

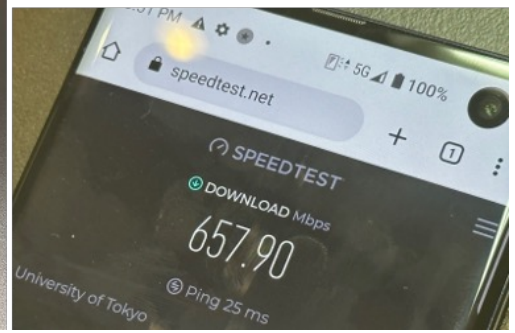
Ultra Compact Local5G Softwarized System

2023/4/25 Press Released

NICT B5G Fund Project “Research and Development of B5G IoT SoC and IoT solution Building Platform of Continuous Evolution”
Grant #00801

- We have developed a low-power (W) integrated core and local 5G system that can be quickly installed outdoors with its small form factor (W) 173.2 x (H) 66 x (D) 274.2 mm (75% of A4 Paper Size)
- The recently announced development of an ultra-compact software-defined radio (SDR) board is embedded in a commercial general-purpose single-board computer to implement 5G functions, resulting in lower cost and flexibility in adding functions through software.
- We will accelerate the solution of social issues, search for potential needs, and value creation through confirming and verifying the usefulness in demonstrations using 5G/B5G communication devices.





4.7-4.9GHz /100MHz Sub6 5G 1W/ch total 2W
2x2 MIMO, Low-Power (90W) TDD SemiSync 1,2,3

Ready-to-use, compact, low-power, high-performance
Internet Directly Connected Local 5G Demonstration System

Press Released 2023/3/31

(Industry-Academia Collaboration among UTokyo, NEC, NEC Platforms)

NAKAO LAB

Integrates local 5G base station, 5G core, and MEC
Software-based, quick functionality update is possible.
Quickly deployable Indoor use (consult us for outdoor use)
Space-saving, low power consumption
- Output: 1 W × 4 ports (Total 4W)
- Size: (W)130 x (H)189 x (D)357 mm (excluding antenna)
- Weight: Approx. 6.2 kg
- Power consumption: Approx. 90 W
Supports semi-synchronous system (TDD1/2/3) (Note 3, 4)

Flare Systems starts selling this unit TODAY!

(Width)130 x (Height)189 x (Depth)357mm

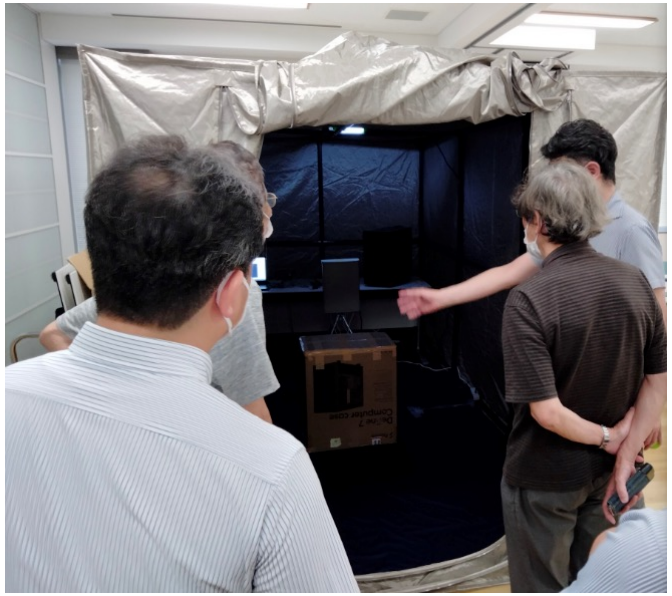
Press Released 2023/4/25

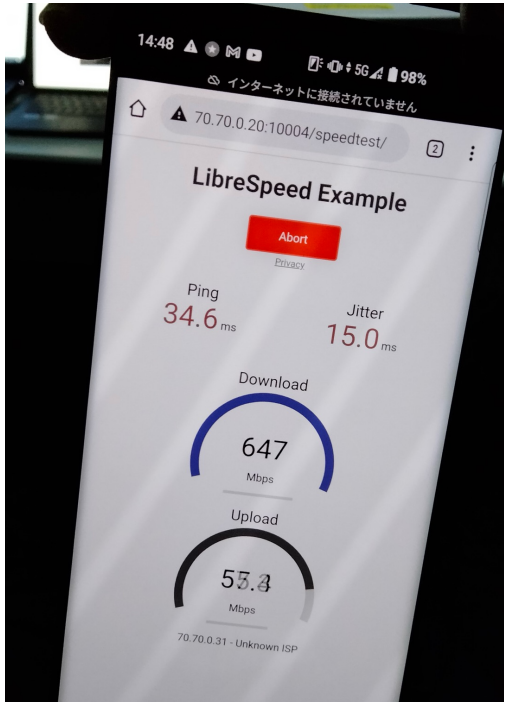
https://jpn.nec.com/press/202303/20230331_02.html

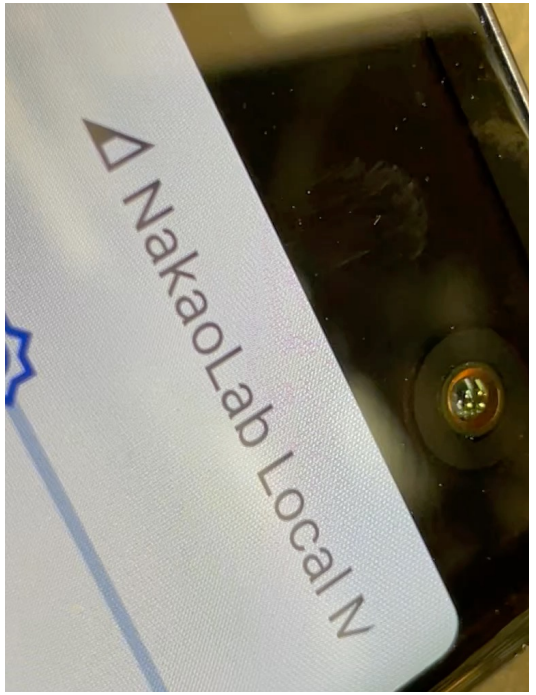

TDD 7:2
TDD 4:4
TDD 3:5
TDD 2:6
LibreSpeed Speedtest
Ping
Jitter
Download
Upload
893
216
579
427
401
549
333
726
NAKAO LAB
FLARE SYSTEMS

(Unit: bps)

Democratizing 5G by Local5G “plugfest”







FLARE SYSTEMS L5G BS

NEC L5G BS

Aprecia L5G BS

L5G UE/CPE

2022/7

Compact 5G base station for deploying local 5G

The University of Tokyo, NEC Group, and local 5G
Developed a demonstration unit for a communication solution capable of mobile and autonomous operation

■Features
Integrates local 5G base station, 5G core, and MEC
Software-based, quick functionality update is possible
Space-saving, low power consumption
- Output ：1 W × 4 Port
- Size ：(W)130×(H)189×(D)357mm
- Weight ：Approx. 6.2 kg
- Power consumption: Approx. 90 W AC100V

Semi-synchronous system supported (TDD1/2/3)

commercialized

Currently available from NEC

2024 at Interop
Winner of the Best of Show Award Grand Prix!

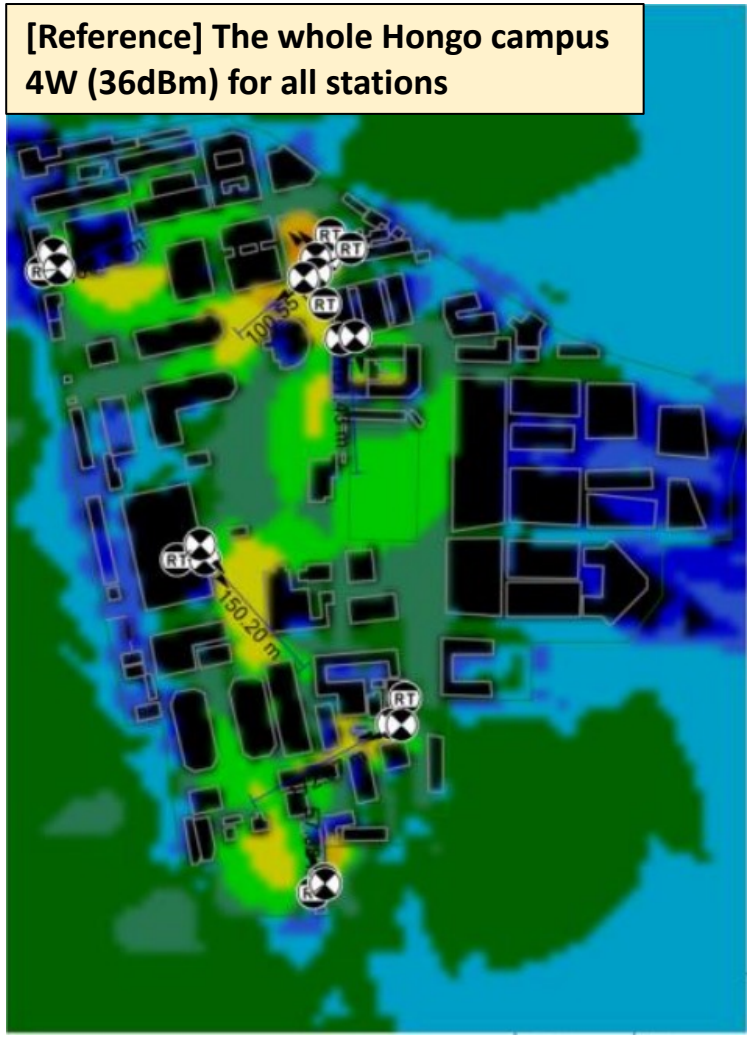
HYPERNOVA

- Savior of the local 5G explosion!
- All-in-one core integrated local 5G system
- Applicable for dual use

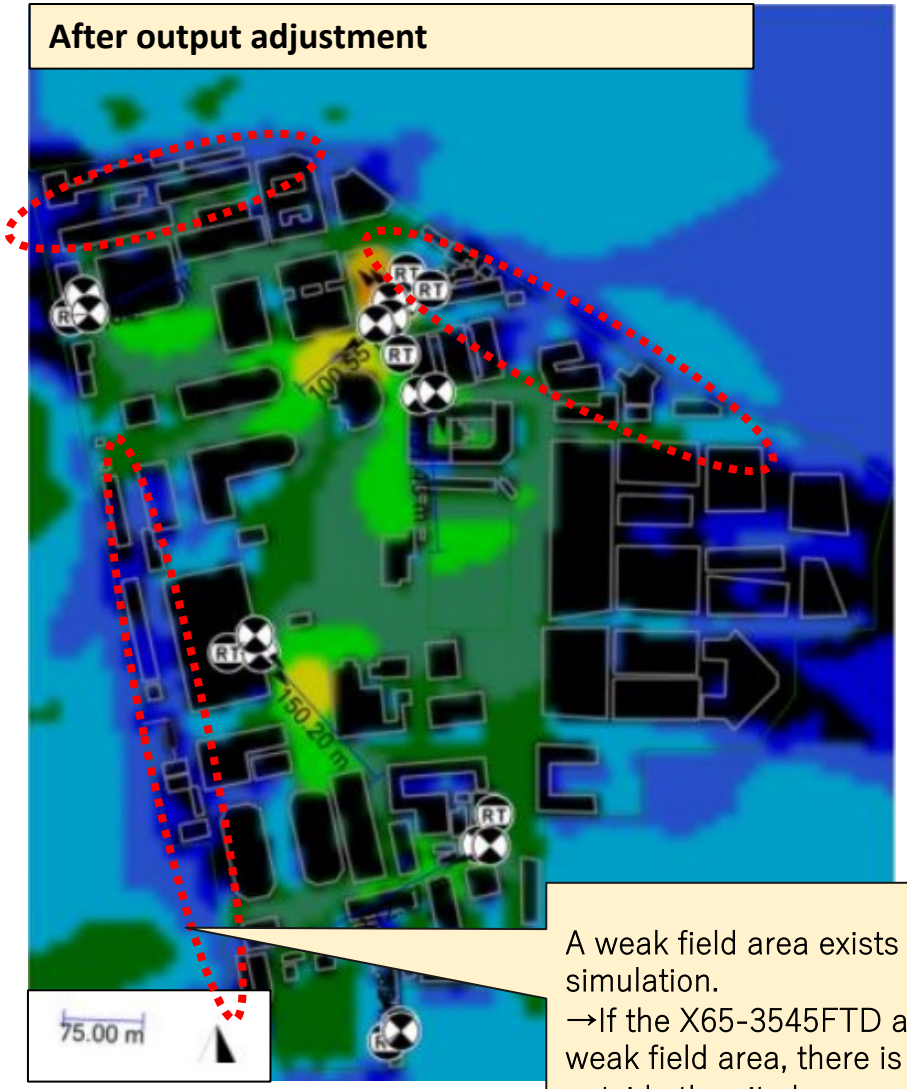
https://www.t.u-tokyo.ac.jp/press/pr2023-03-31-001
https://f2ff.jp/2024/interop/award/winner/?_ga=2.150817460.364030637.1718167308-839236177.1717590680

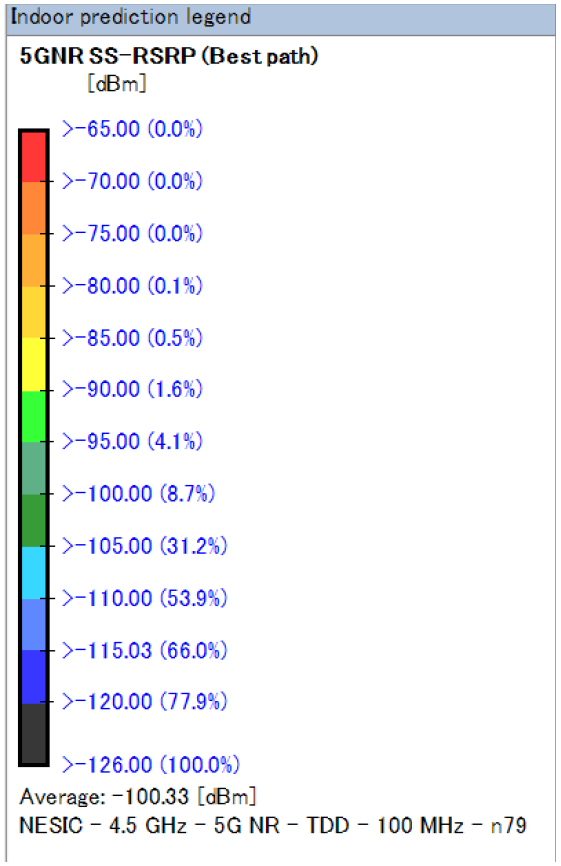
Hongo Campus Deployment: Simulation Results

[Reference] The whole Hongo campus 4W (36dBm) for all stations



After output adjustment





A weak field area exists at the edge of the site in the simulation.
→If the X65-3545FTD antenna is installed in the weak field area, there is a possibility of leakage outside the site because the beam width is 60° .

Dynamic Spatio-Temporal Slicing

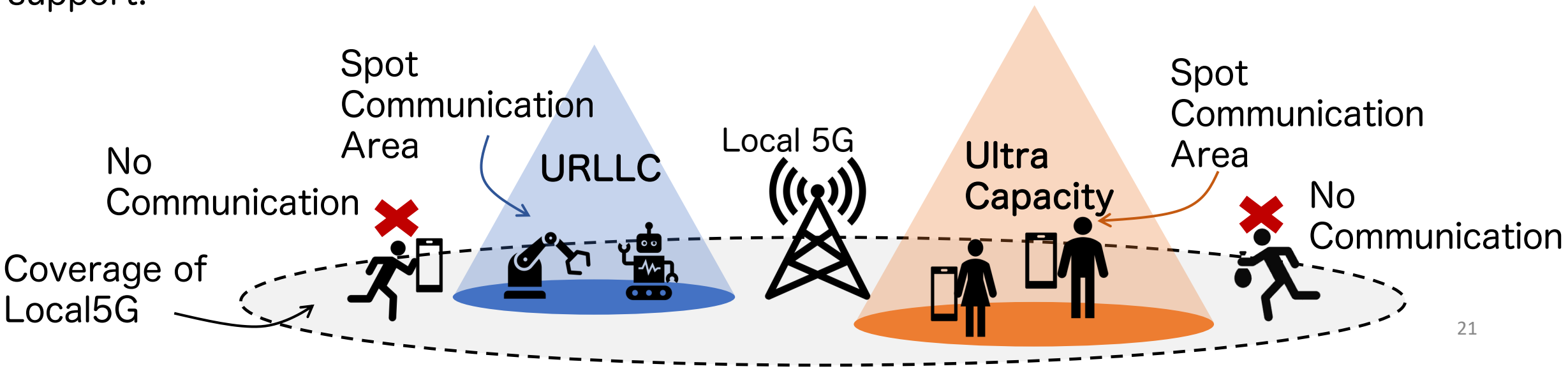
NAKAO LAB NEC

Problem: From the perspective of cyber security, information leakage and hacking due to radio wave leakage have become a social problem. It is required to control the availability and quality of communication in a limited and spatially detailed area.

Proposal: Local 5G that enables flexible communication control based on newly assigned "information" to data flowing over the communication channel.

- Location measurement information enabling a **spot** communication area
- Terminal authentication information enabling a **secure** communication area

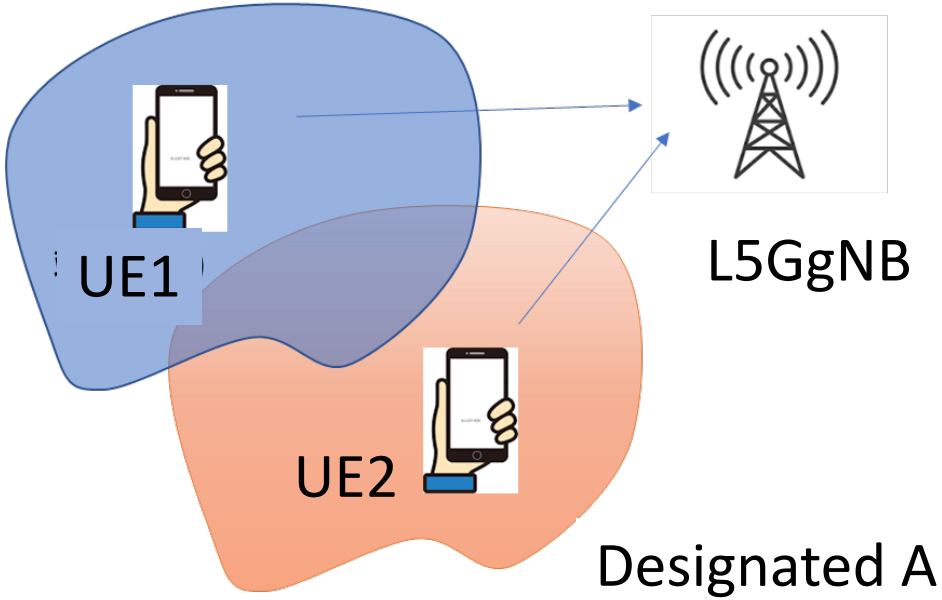
Value: Establish safe and secure information and communications for use in industry and life support.



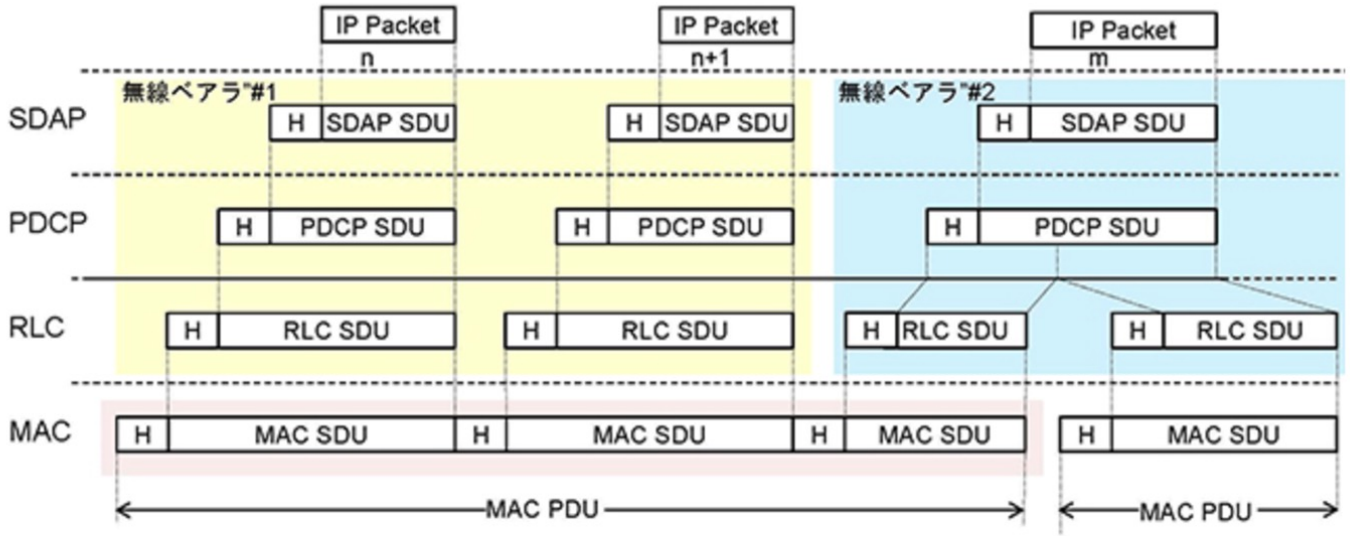
Dynamic Spatio-Temporal Slicing

- Designing Base Station Architectures to Control Communication Quality in a Defined Space
- Technology that enables communication only in a limited space is important for security purposes.
- The established technology enables positioning with an accuracy of several centimeters to several tens of centimeters using UWB radio, and the positioning information is added to the header of the radio protocol to control the quality of communication (especially throughput and availability) by controlling the frame on the base station.
- This technology has been applied for a patent during FY2022 (Patent Application 2022-170194).

Designated Area1



Designated Area2



U-Plane Data Frame Structure

A Local 5G Usecase : Enabling Local Government Revitalization

There are still more than 100 people facing climing accidents every year

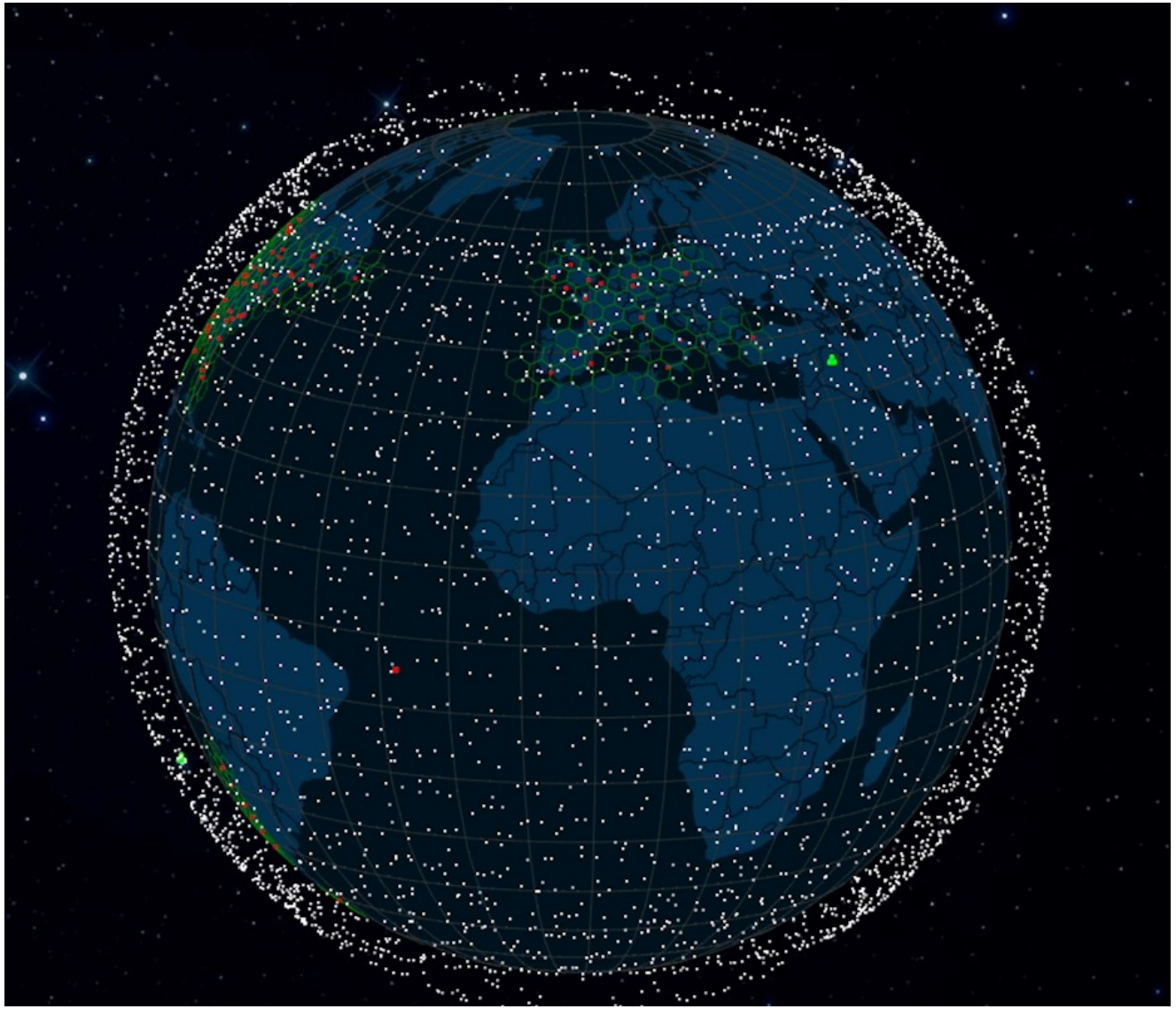
Local 5G x NTN : Private5G and Satellite Internet Access Service for Disaster Countermeasures and Disaster Mitigation at Mt. Fuji for use in disaster countermeasures and disaster mitigation (Local Government Revitalization)

Press Released on 2022/11/25

NAKAO LAB

https://www.t.u-tokyo.ac.jp/press/pr2022-11-25-002

Internet Service via Low Earth Orbit Satellite Starlink



https://satellitemap.space

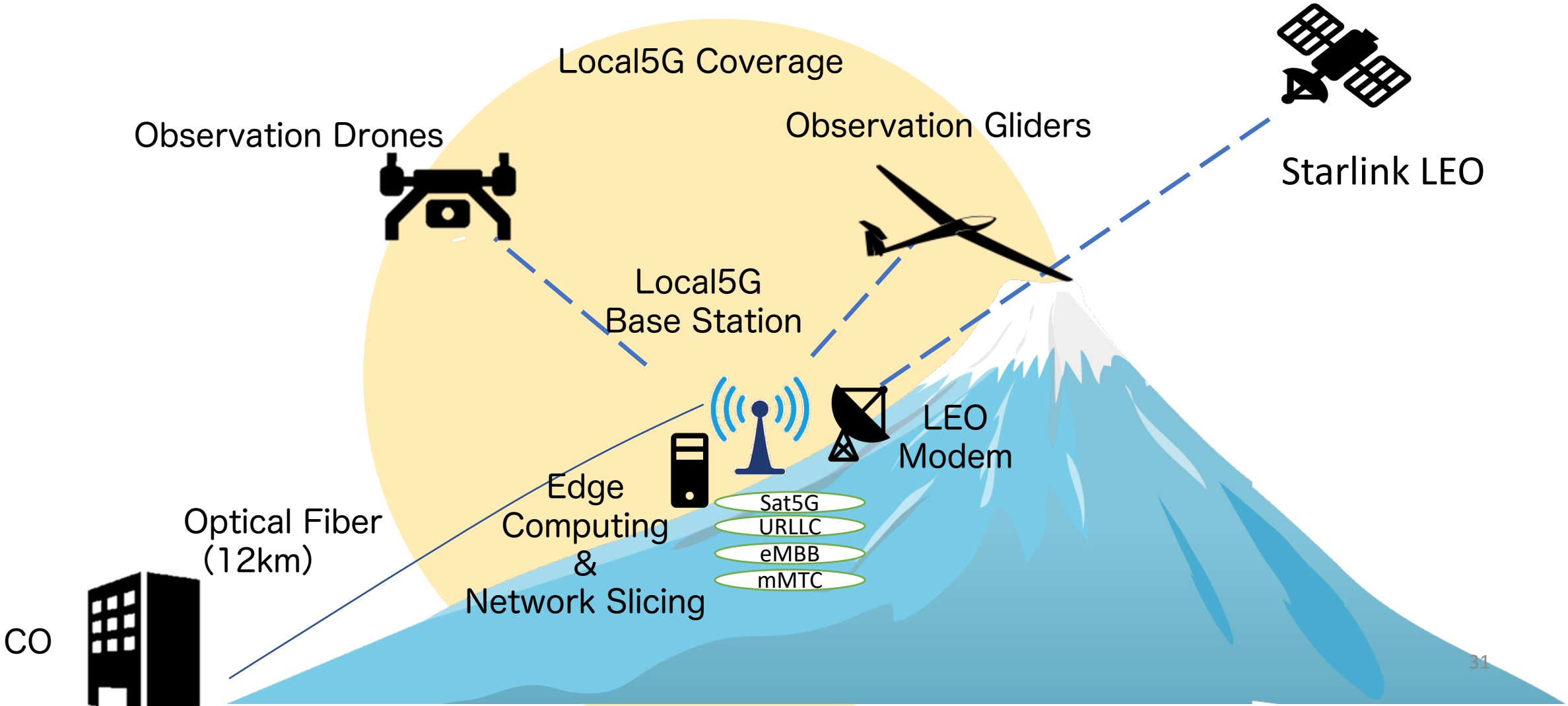
Starlink is operated by SpaceX.
It is a low earth orbit satellite Internet service.
Enabling high-speed, low-latency satellite Internet access to almost anywhere on the planet.

It currently consists of more than 6,000 small satellites. The satellites, which have reduced manufacturing and launch costs through miniaturization and mass production, provide low-cost satellite Internet access services that do not depend on the ground infrastructure of the user's residence by connecting the user's dedicated wireless communication terminal kit with ground stations in various countries.

Total cost is more than $10 billion
(1.4 trillion yen)

LEO x Local 5G Use Cases at Mt. Fuji

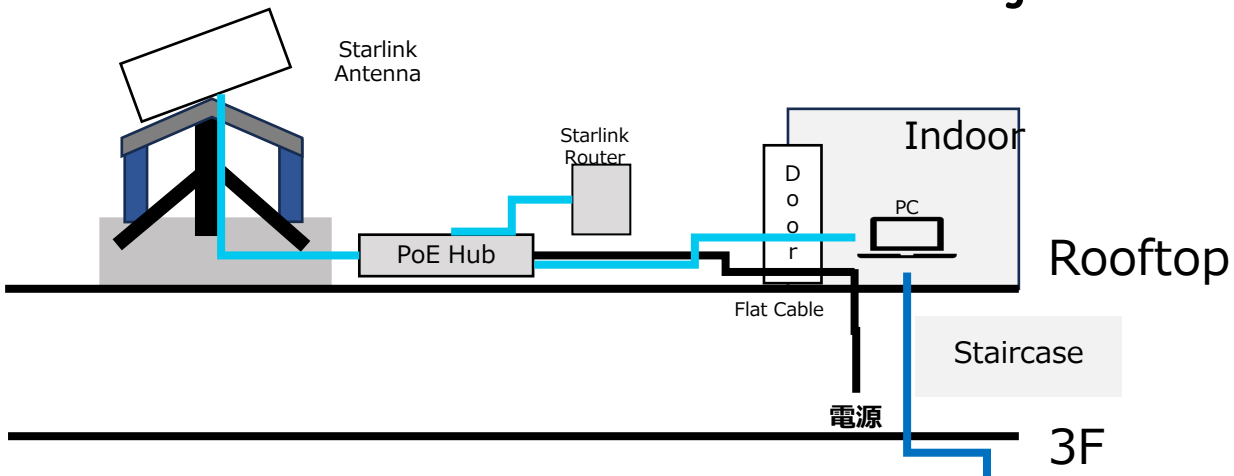
Challenges: Harsh Environment (Windy/Stormy/Low Temp/No Electricity)
Values: Surveillance / Security



LEO communication quality measurement environment at Mt. Fuji

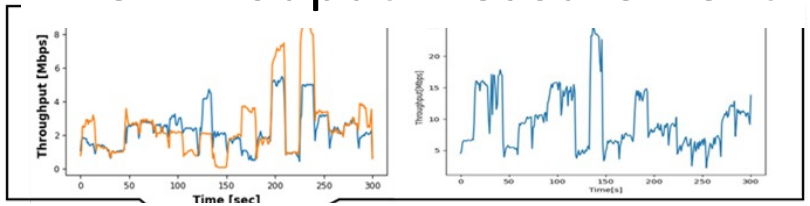
Mt. Fuji 5th Level

Measurement Gears on Rooftop



Mt. Fuji 5th Level

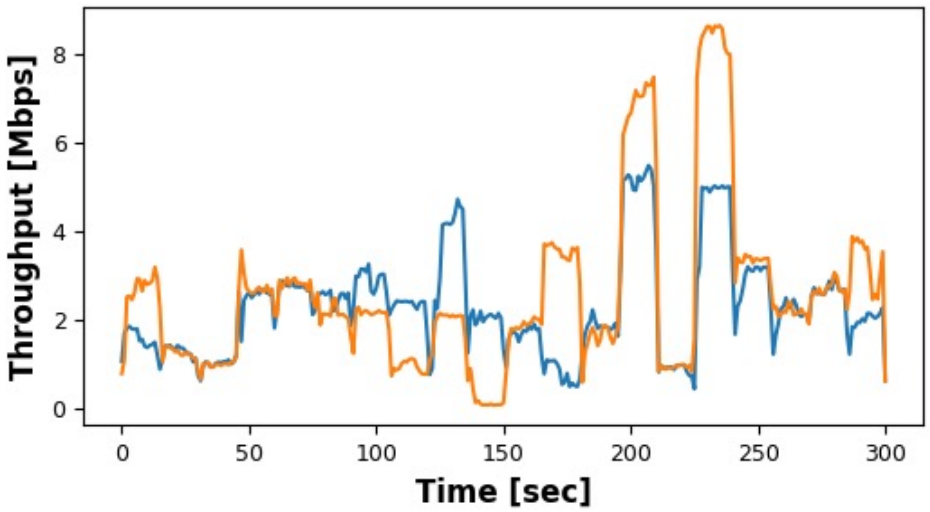
LEO Throuput Measurement



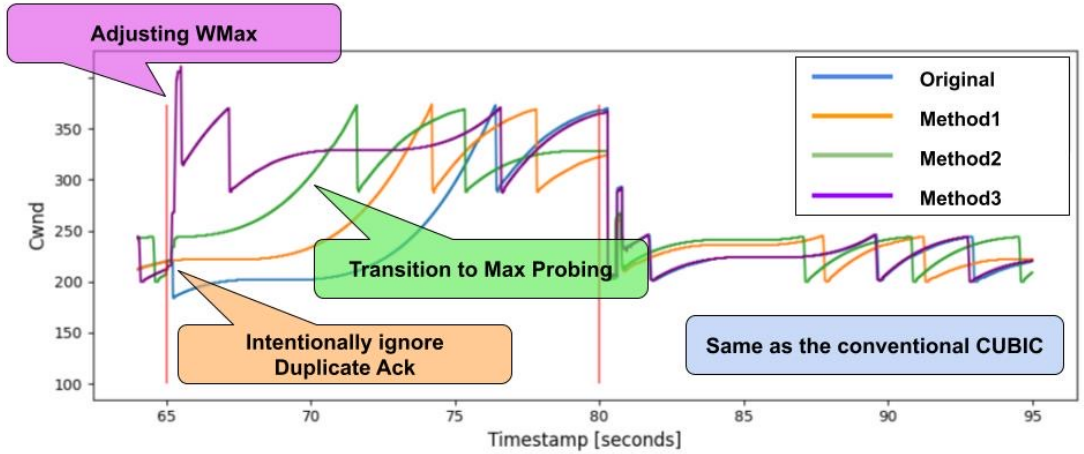
NakaoLab at UTokyo

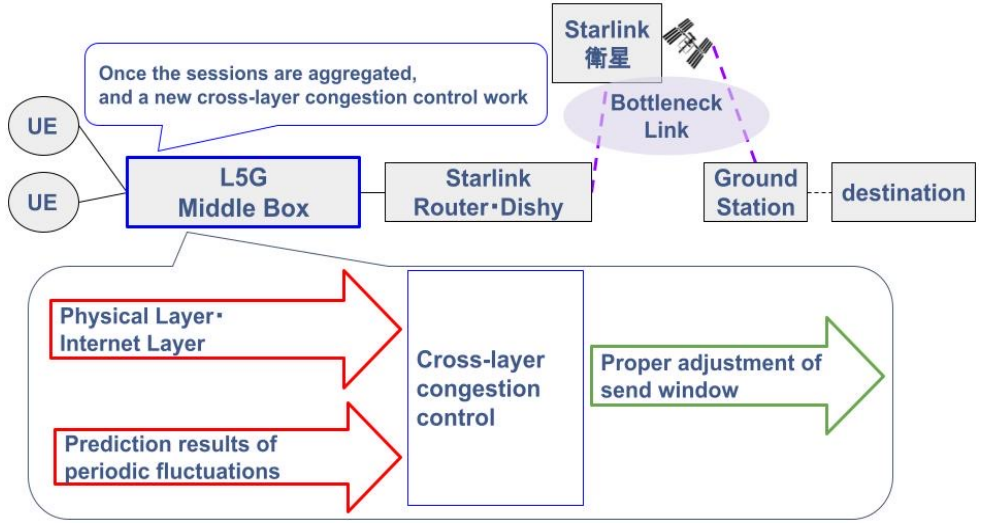
QoS control for effective interconnection of satellite communications, etc.
Customization of mobile systems in local 6G for the purpose of
Communication measurement and communication quality modeling

End-to-end Architecutre Optimization for New Radio (NR)



Throughput Fluctuation in Starlink LEO





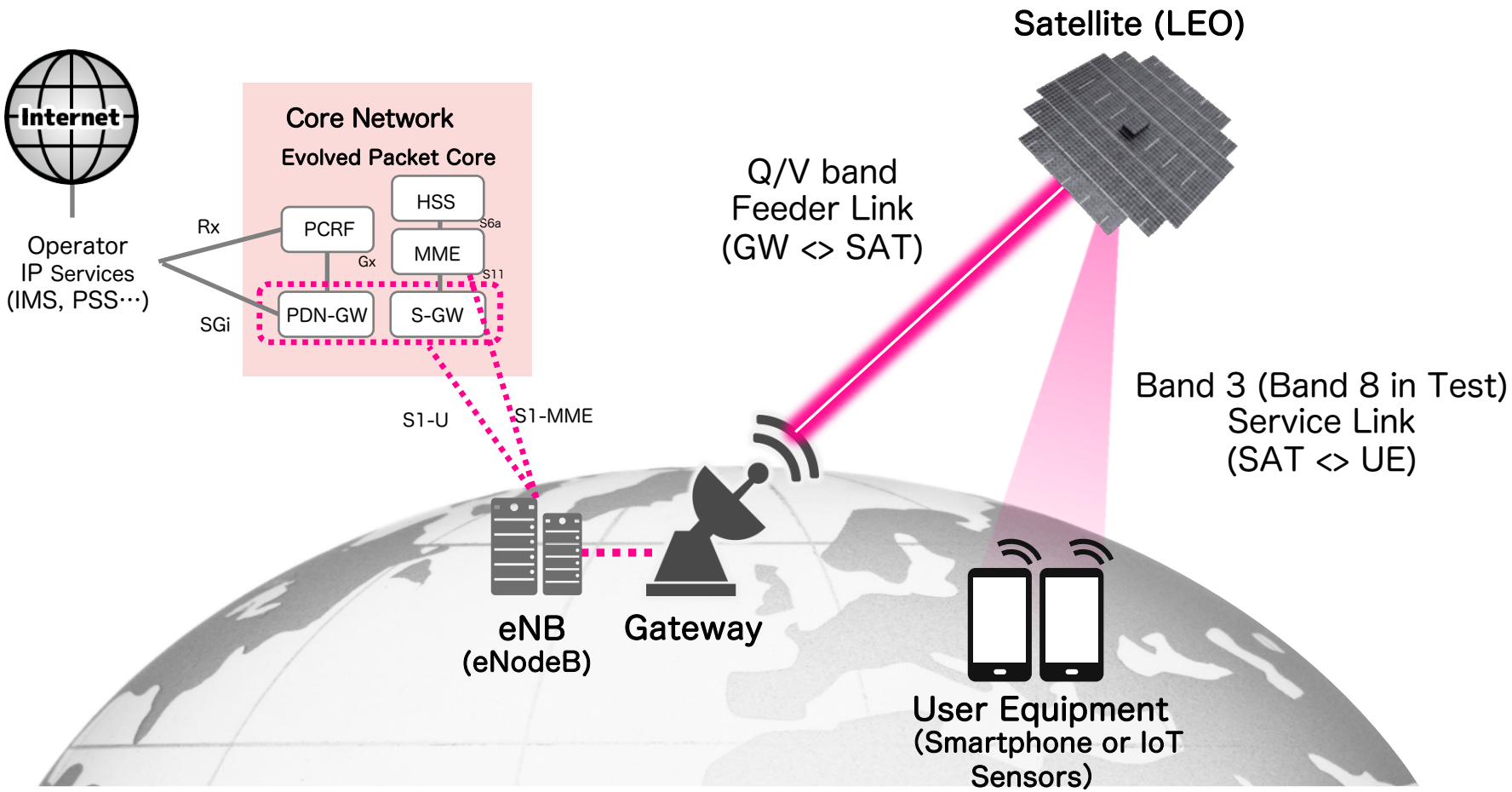
Local5G + LEO Integration Architecrure

Proposal	1	2	3
Maximum Throughput Improvement Rate	15%	22%	**25%**
Capacity Nodes	3	5	**10**
Fairness (Jain's Fairness Index)	**More** than original		**Less** than original
Congestion Collapse	**NO** congestion collapse		
Prediction of Starlink status (Cross-layer information)	Increase or decrease		Rate of fluctuation

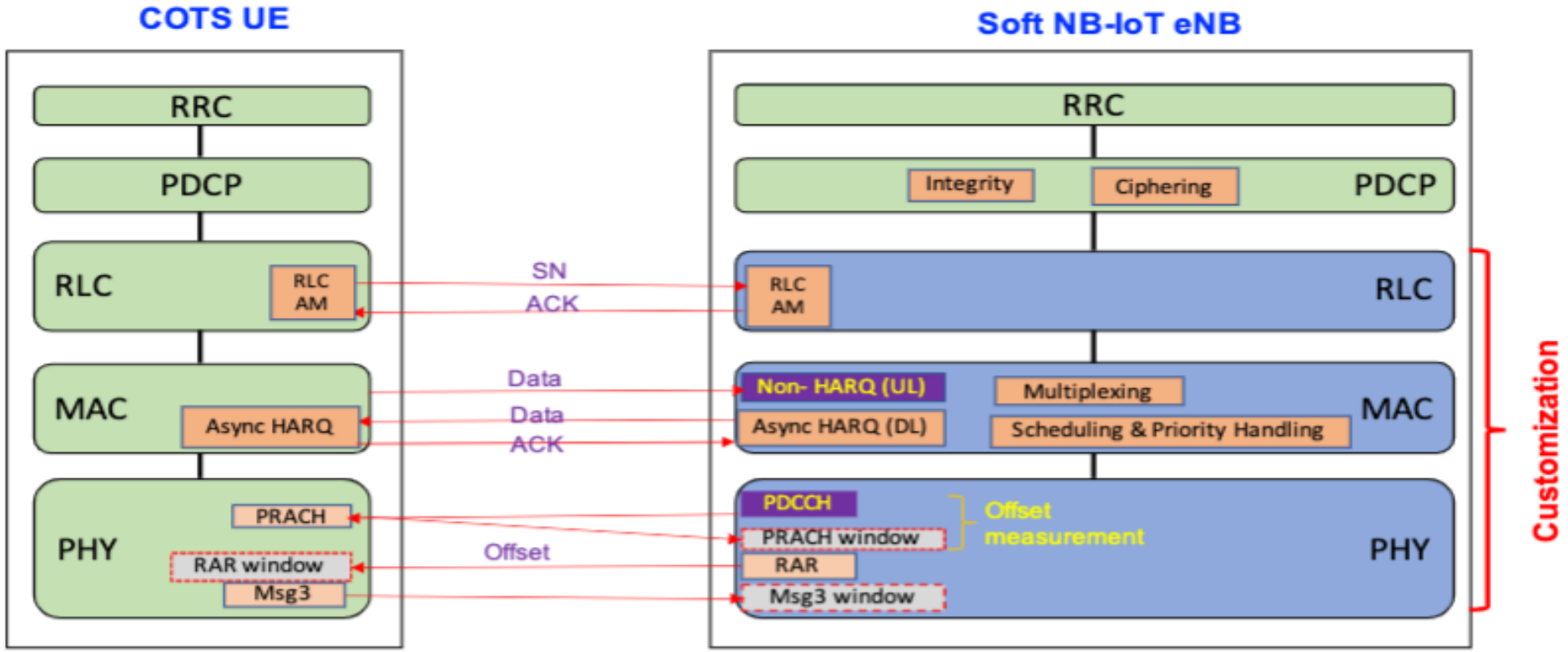
New Cross-layer Congestion Control achieves up to 25% throughput improvement!

“Mobile Direct” Project Rakuten/AST Mobile and UTokyo

- Base Stations and UE communicates via Satellite.
- Doppler shift and delay are processed on the ground so that unmodified UE (User Equipment) can communicate with each other wherever they are!



Delay Compensation Design for NBIoT



- PHY Layer
  - When UE receives a PDCCH signal, it sends back a RACH signal for Random Access.
  - The eNB receives the RACH, it can calculate the propagation delay between eNB and UE.
  - The eNB can inform the UE about the propagation delay via RAR signal.
- MAC Layer
  - We use Synchronous HARQ for uplink and Asynchronous HARQ for downlink.
  - We need to disable the HARQ in uplink in the MAC layer.
- RLC Layer
  - We need to enable RLC-AM (Acknowledge mode) in the RLC layer.
  - Each RLC frame can be ACKed so that lost RLC subframes from UE to eNB can be retransmitted.

BlueWalker3 Test Satellite

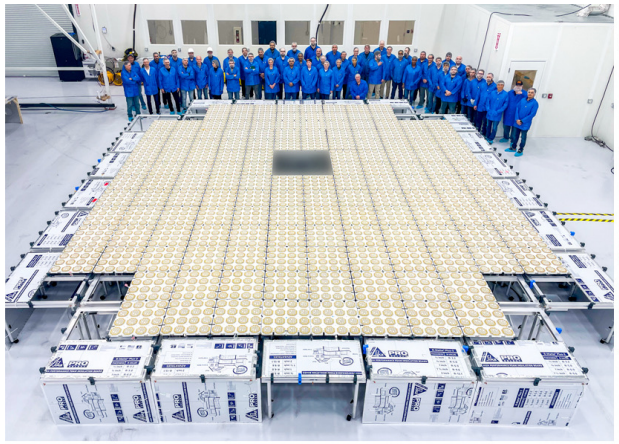
Jul 2022
- Transported BW3 to California for testing
- Successfully completed enviormental testing

Aug 2022
- Transported BW3 to Cape Canaveral, FL for final preparations and continuation of testing

Sep 2022
- On Sep 11 JST Falcon 9 launched from Cape Canaveral, FL

Nov 2022
- BW3 placed into orbit
- Initial in-orbit testing
- Unfurl phased array
- Deploy QV antennas

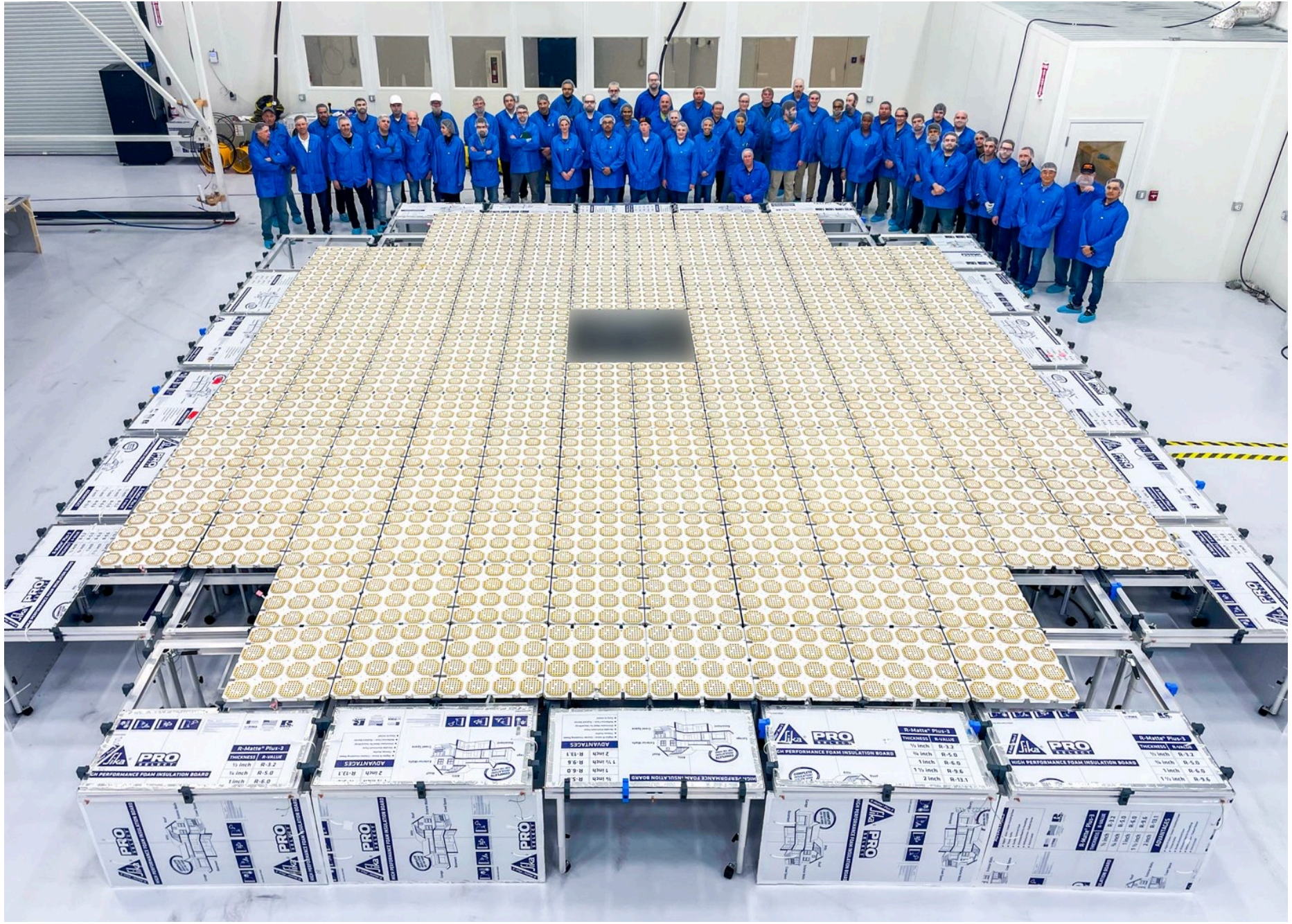
Mar 2023
- Cellular broadband direct-to-cell phone testing on standard handsets, in cooperation with participating MNOs on 6 continents



https://ast-science.com/2022/08/09/ast-spacemobiles-bluewalker-3-test-satellite-arrives-at-cape-canaveral-for-upcoming-launch/

Successful launch on Sep 10, 2022

https://ast-science.com/2022/09/13/ast-spacemobile-confirms-successful-launch-of-bluewalker-3-into-orbit/



https://twitter.com/AbelAvellan/status/1504920229868101639/photo/1

Inclusive Creation of Next Generation Cyber Infrastructure

Objective:

In this research proposal, international collaborative research will be conducted with an inclusive approach where all stakeholders participate in the research to establish fundamental technologies for next-generation cyber infrastructure even more robust as social infrastructure.

Specifically, we will promote "Local 6G," where we promote local networks to drive various innovations locally and promote them to drive the evolution of the entire information and communication field by quickly identifying and demonstrating the value of useful technologies through campus testbed collaboration.

We will establish a sustainable top researcher network by horizontally expanding the top researcher circle in this research field to like-minded countries, with Japan and Finland as the core, and vertically expanding them between generations.

Ultimately, we strategically focus on the early experience of young researchers in international collaborative research and the formation of human networks through participation in collaborative projects. The goal is to contribute to the continuous cultivation of globally distinguished human resources in the field of information communication in Japan.

Partners

University of Oulu

Artificial Intelligence Graduate School

Sorbonne Université

Technische Universität Berlin

Platforms for Advanced Wireless Research

Fraunhofer FOKUS

Northeastern University

Rutgers, The State University of New Jersey

University of Cape Town

Virginia Tech

University of Surrey

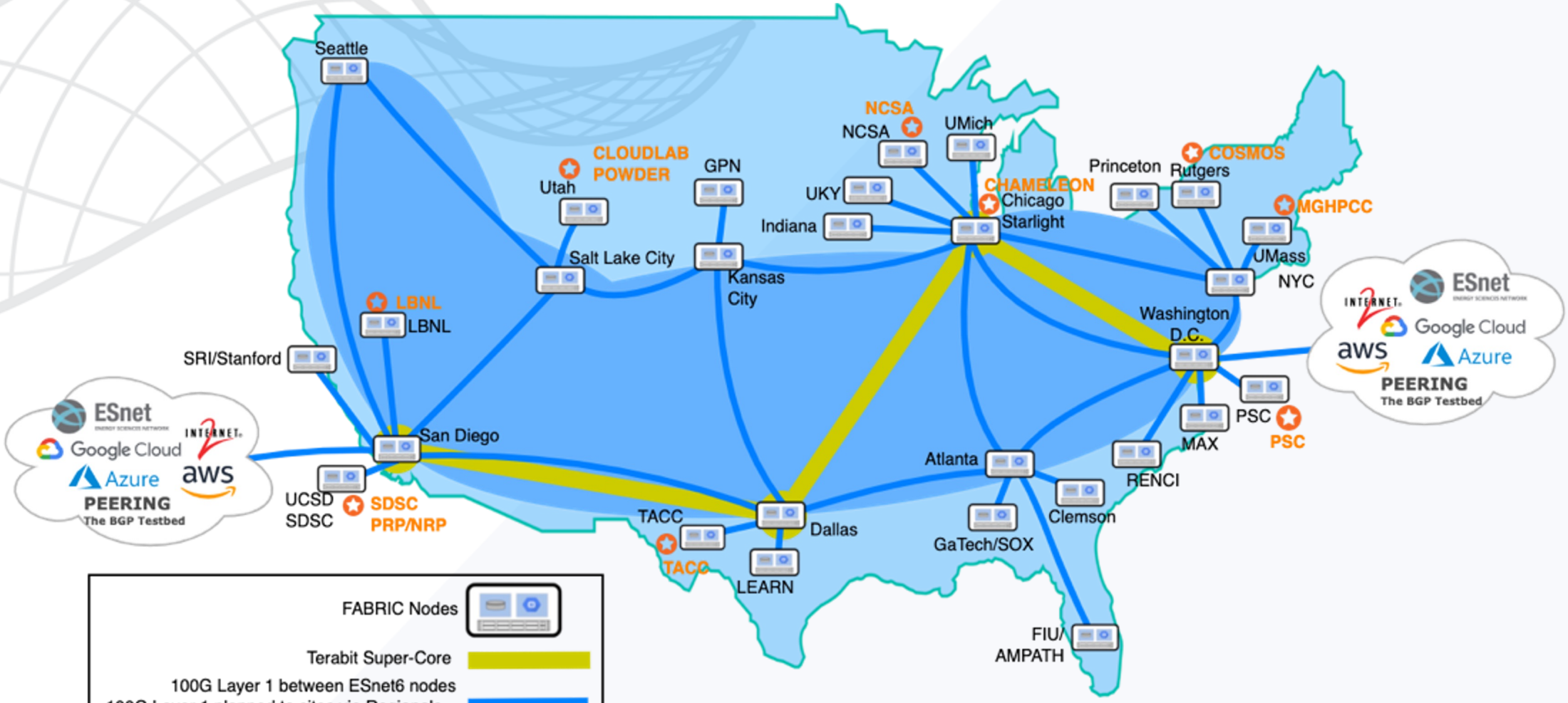
Clemson University

New York University

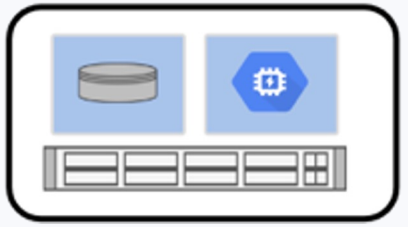
Karlstad University

EURESCOM

FABRIC Topology



FABRIC Node
Programmable Networking
Compute (CPU,GPU,FPGA)
Storage



FABRIC

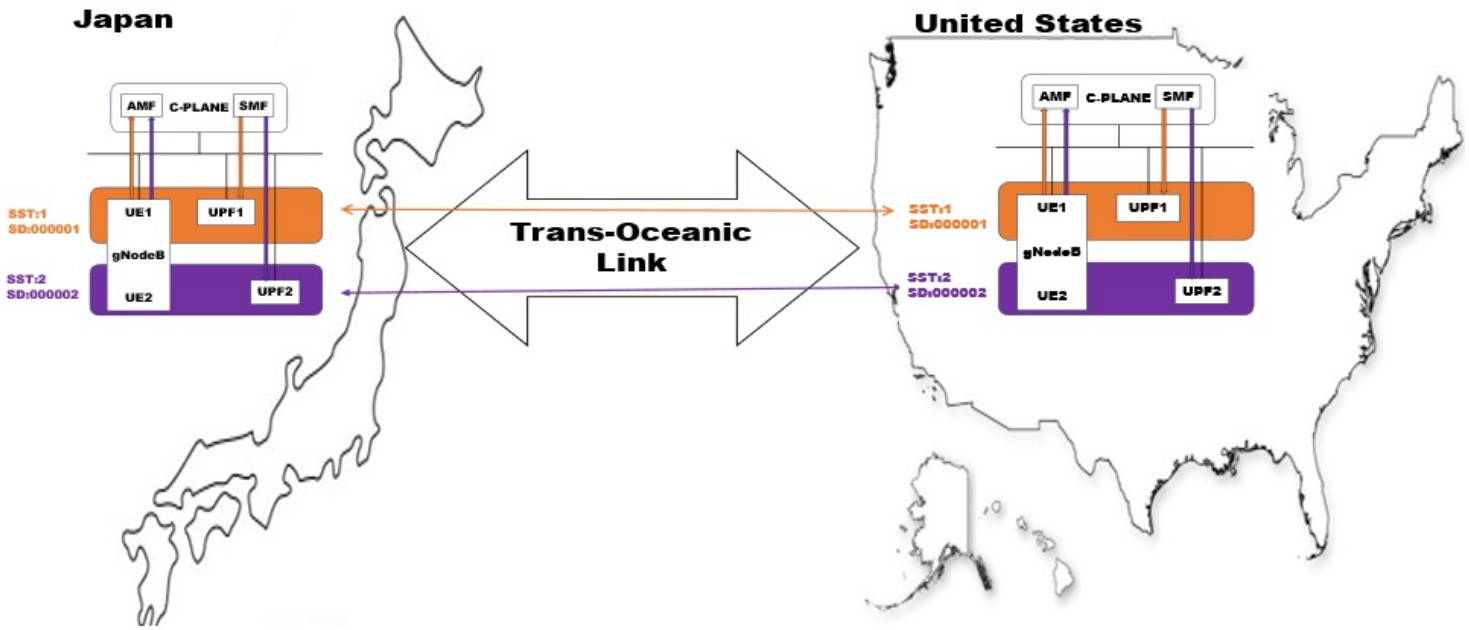
FAB

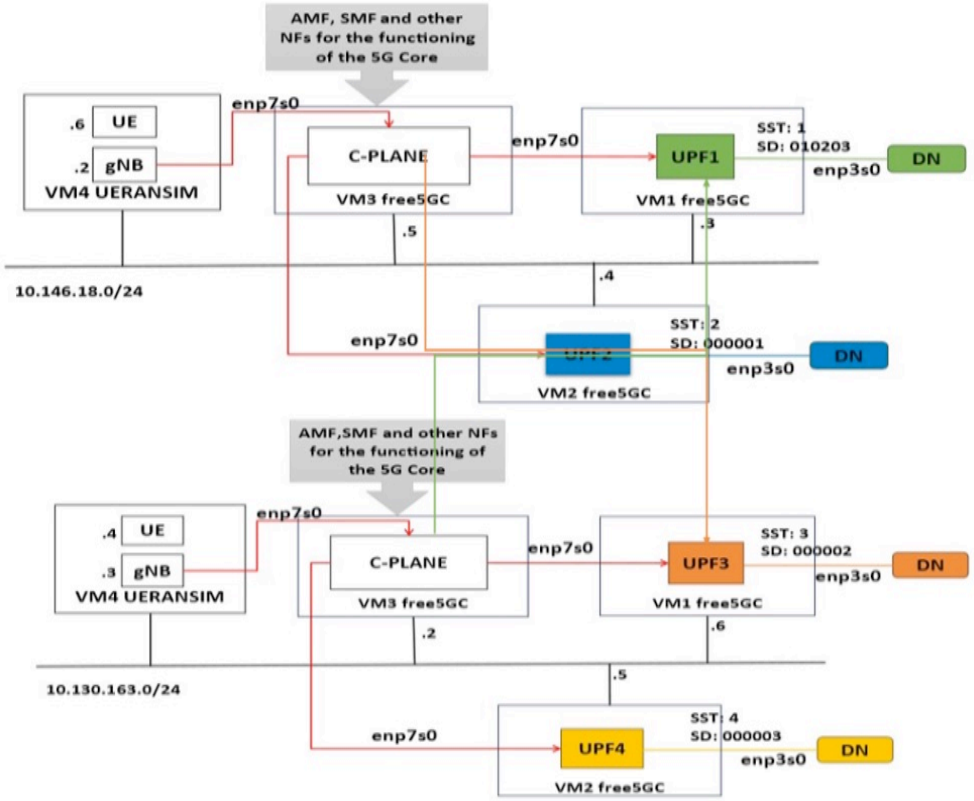
FABRIC Node in NakaoLab



FABRIC is an international infrastructure designed for large-scale experiments and research in areas such as networking, cybersecurity, 5G, and machine learning. It comprises 29 sites equipped with high-performance computing resources and storage, all interconnected via high-speed optical links. Additionally, FABRIC has been expanded as FABRIC Across Borders (FAB), with four nodes located in Asia and Europe.

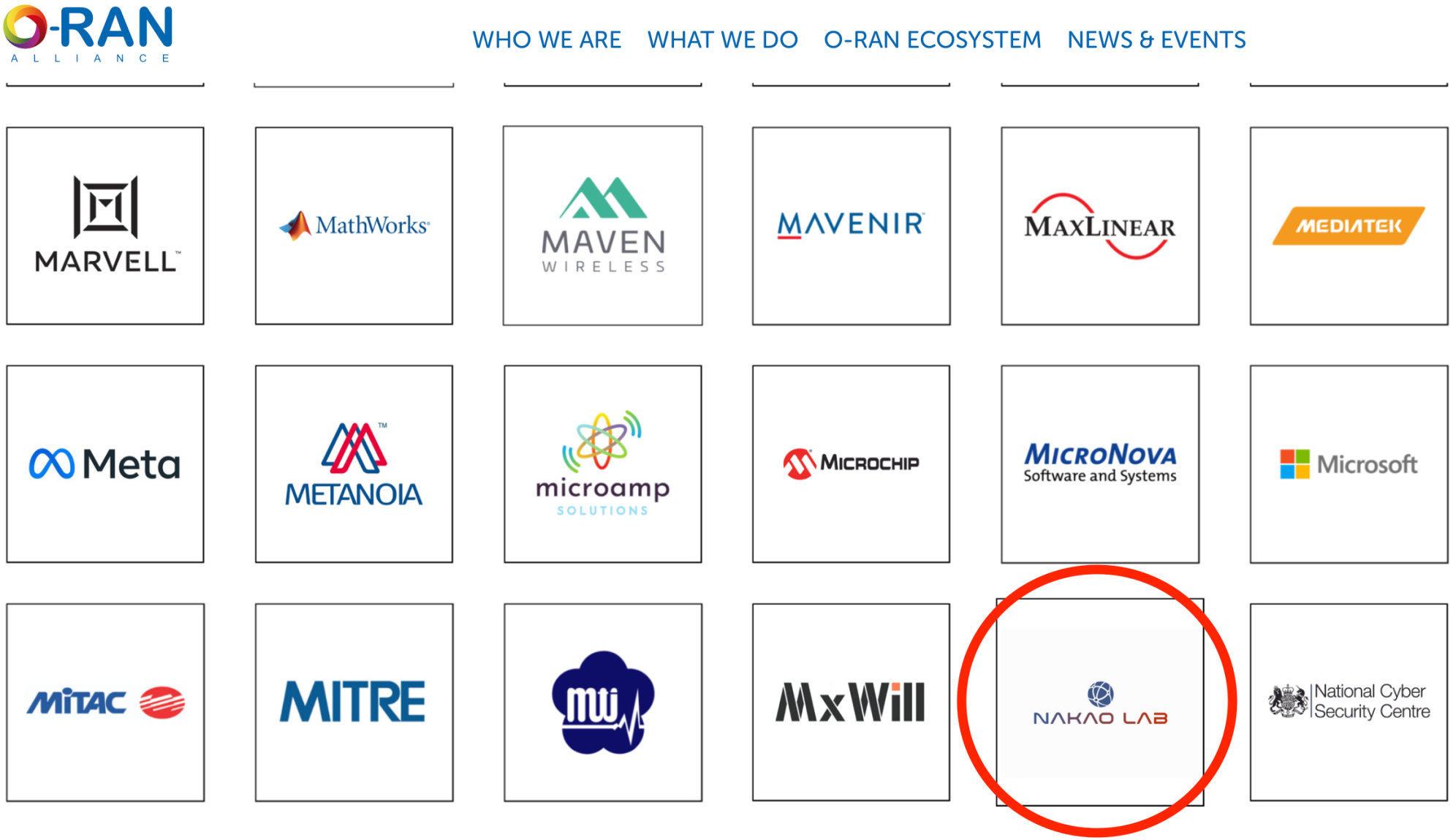
Extending Local5G Networking over Transcontinental Network Slicing





- Two Local5G hotspots were established in Tokyo, Japan, and Dallas, USA, interconnected via a trans-oceanic link.
- Utilized FABRIC infrastructure for experimentation, with Free5GC for core network functionalities and UERANSIM for simulating user equipment and gNodeB interactions.

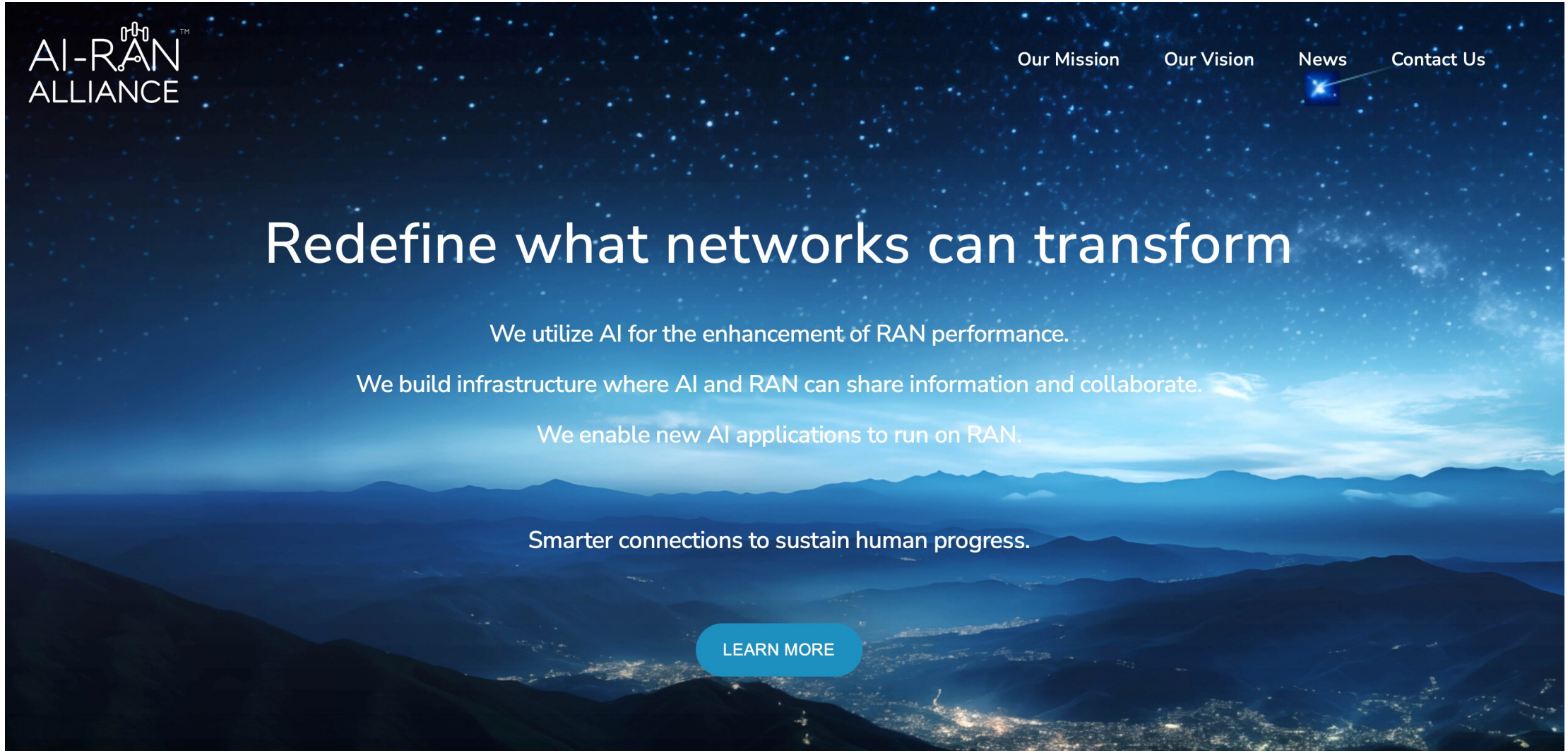
O-RAN Alliance Member (NakaoLab)



NakaoLab is already a member and hosts plug fest in May and now plans to be the secretariat for Utokyo membership

O-RAN Global PlugFest Spring 2024

AI-RAN Alliance (UTokyo)



We, Utokyo, plan to become a member of AI-RAN Alliance soon.

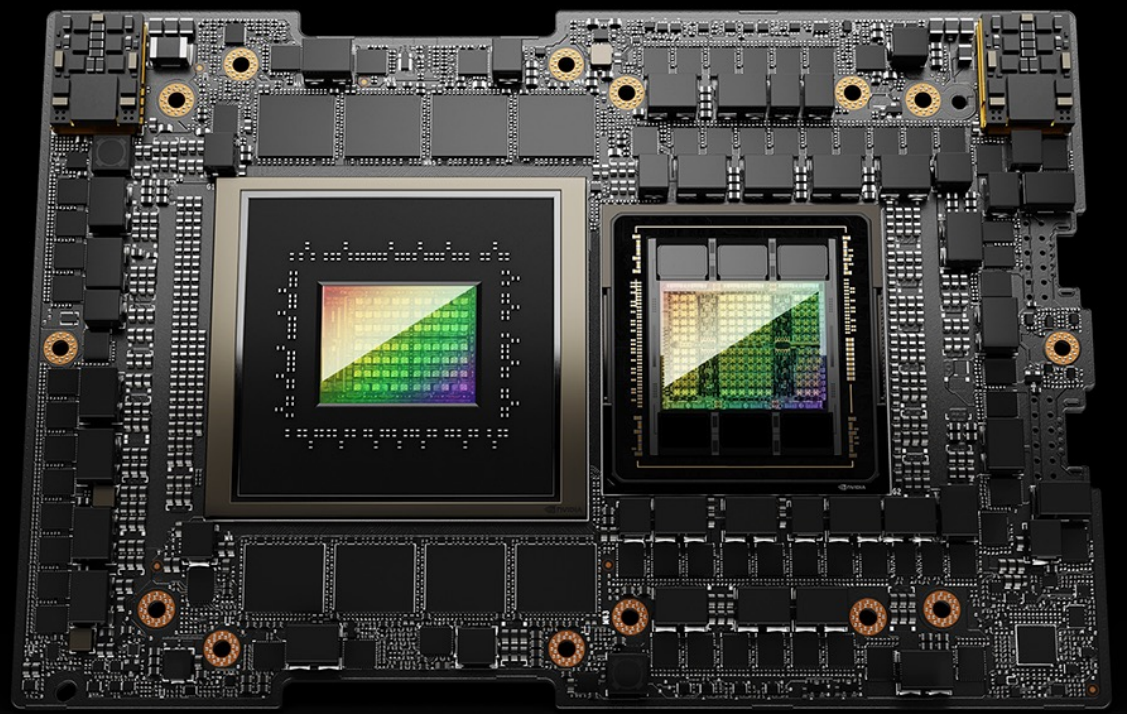
Founding Members

https://ai-ran.org/

Cloud & Data Center Solutions Products Data Center GPUs Software •••

NVIDIA GH200 Grace Hopper Superchip

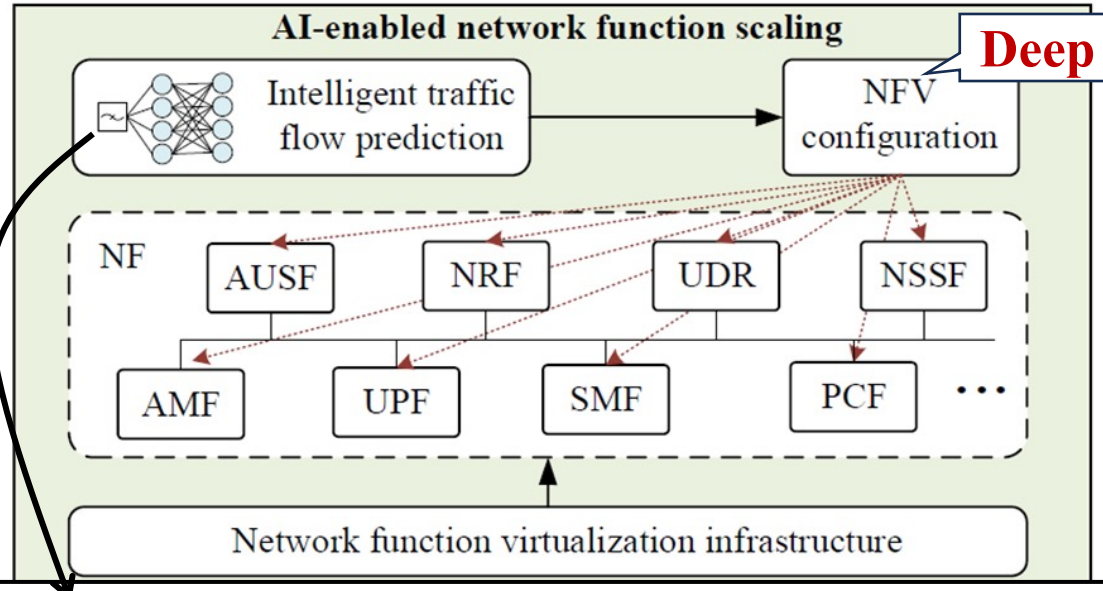
The breakthrough design for giant-scale AI and HPC applications.



https://www.nvidia.com/en-us/data-center/grace-hopper-superchip/

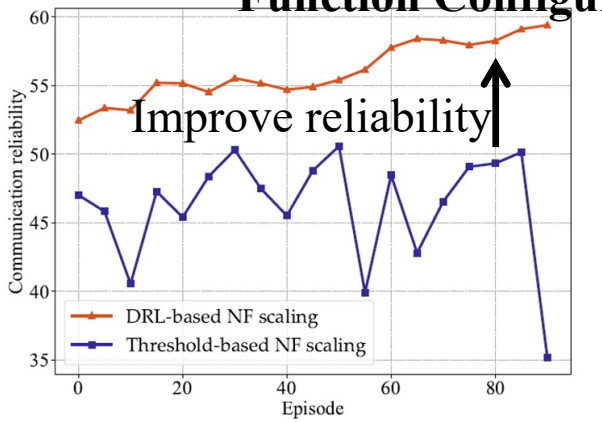
AI-enabled robust and resilient 5G system

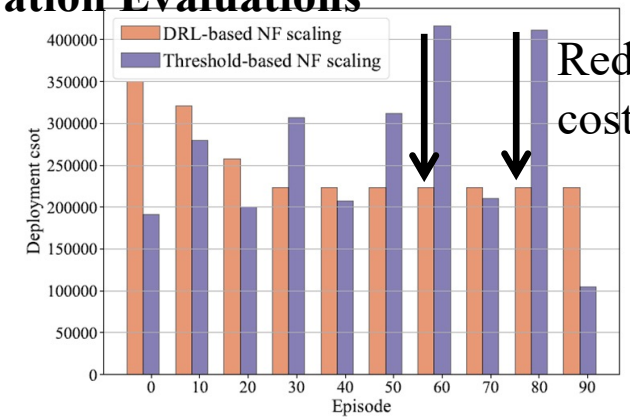
➢AI-enabled **Traffic Flow-Prediction** and **Function-Configuration**



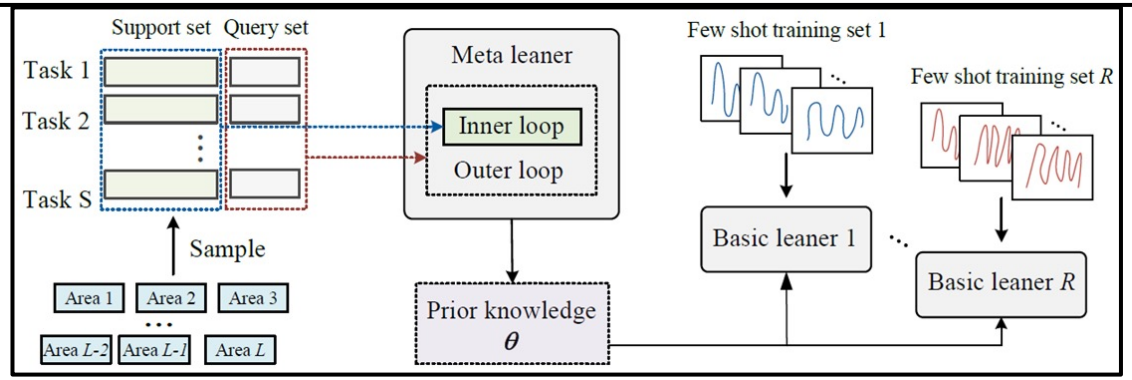
Deep Reinforcement Learning-based resource allocation of NFs

Function Configuration Evaluations

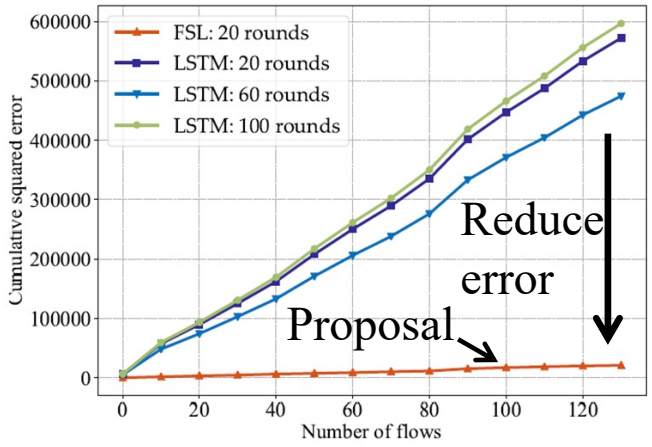


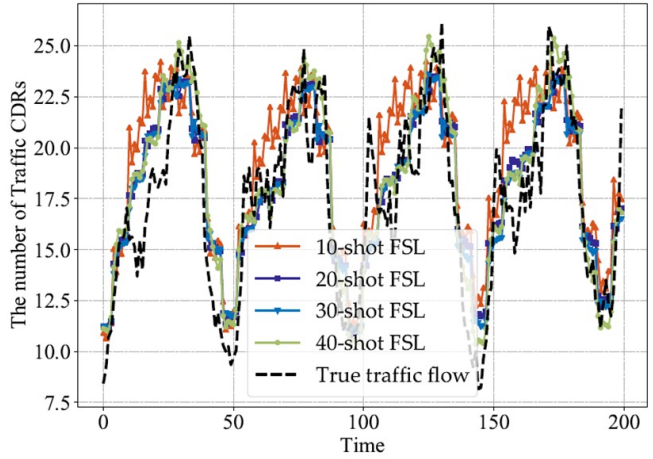


Few Shot Learning-based Traffic Flow Prediction



Traffic Flow Prediction Evaluations



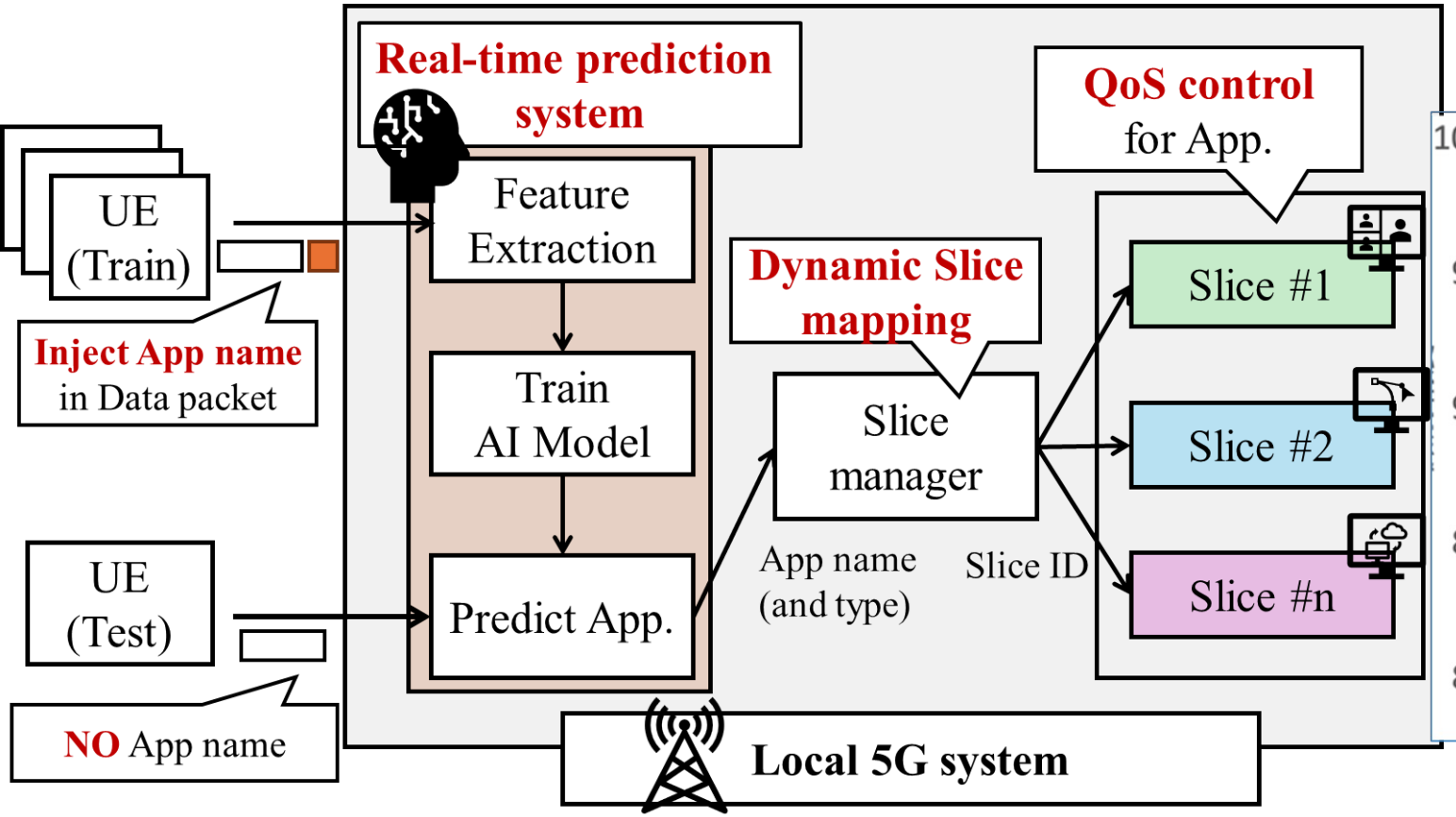


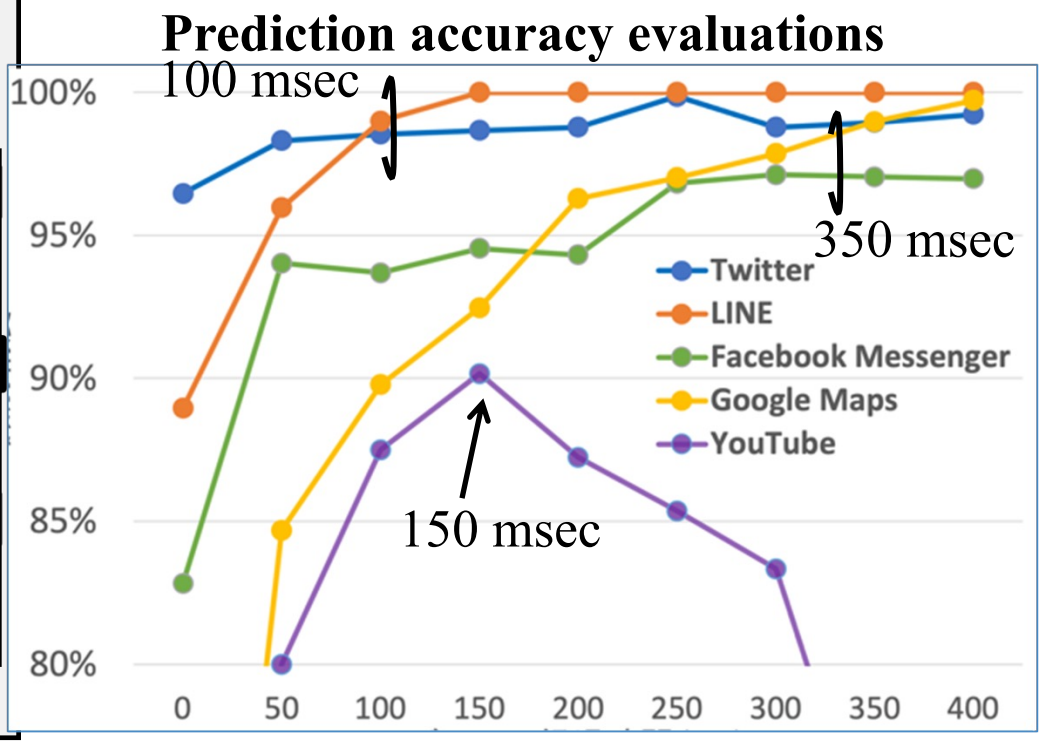
Q. Pan, A. Nakao, ” AI-enabled Traffic Flow-Prediction and Function-Configuration for 5G Networks: An Integrated Design of High Reliability and Low Cost” IEEE ICC 2024. (accepted).

AI-enabled network slicing for optimization of Application QoS

➢**Realtime AI-based application prediction** for autonomous network slicing

- ✓ Collect **60** UEs for **one** month
- ✓ Include **298** Apps.
- ✓ Proposal can predict **100-350 msec** to predict typical network apps. with **90% accuracy**



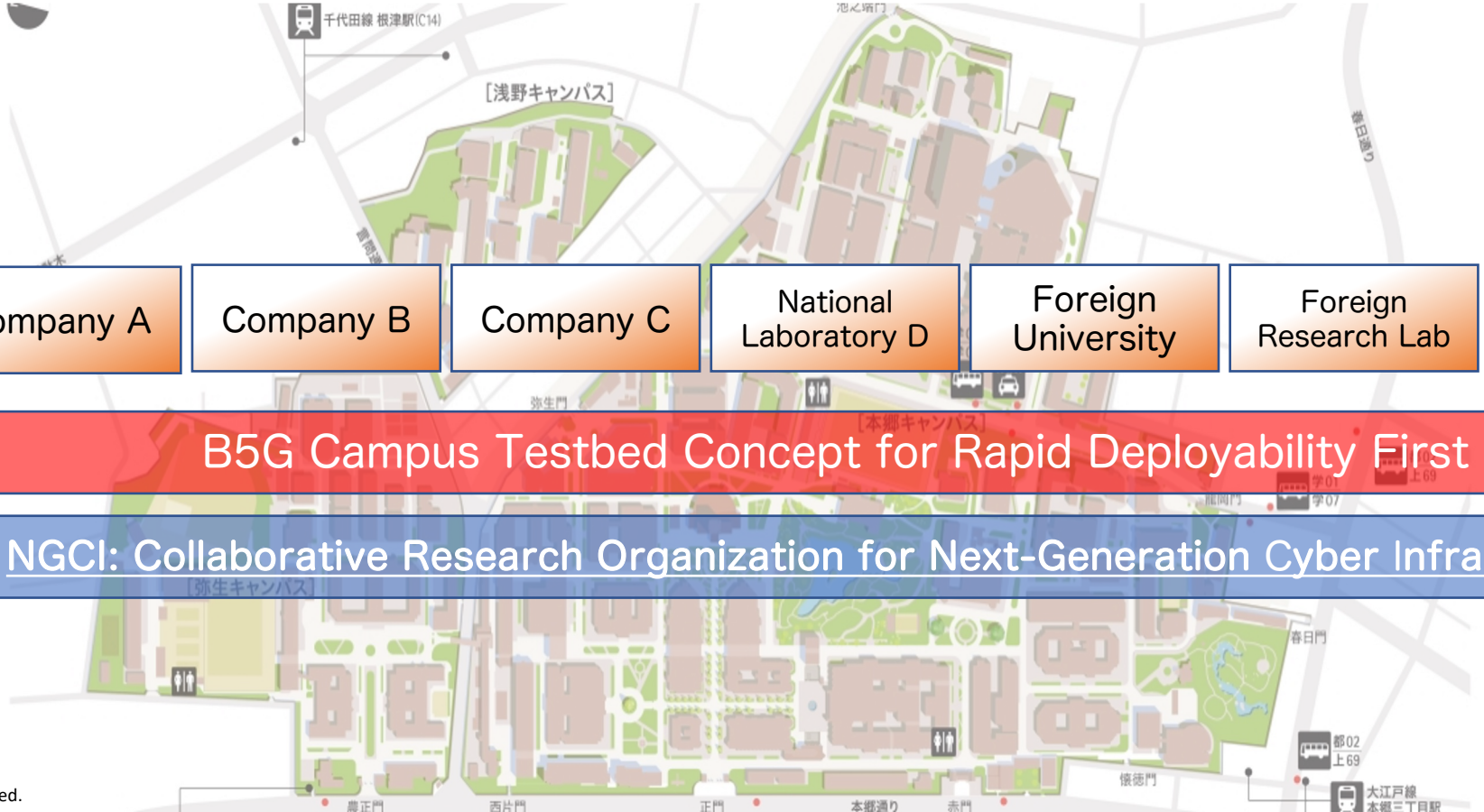


T. Ou, K. Kanai, A. Nakao, ”Real-time Application Identification Scheme and Evaluation Method Using Machine Learning” IEICE Tech. Report, Mar. 2024.
Tatsuhiro Ou, Akihiro Nakao,"Real-Time Application Identification Method for Mobile Networks Using Machine Learning",to appear in IEEE/IFIP International Workshop on Analytics for Network and Service Management (NOMS_AnNet 2024)

Conlusion: Democratizing 6G Innovations

involving all stakeholders from industry, academia, government, and private sector

- Testbed for democtratizing B5G network technologies
- Verification of social acceptability of technology
- Human resource development and industry-academia human resource circulation
- Promote interactive international collaboration to attract outstanding human resources



Closed Competitive Domains

Company A	Company B	Company C	National Laboratory D	Foreign University	Foreign Research Lab	Standardization Body

Open Cooperative Domain

B5G Campus Testbed Concept for Rapid Deployability First

NGCI: Collaborative Research Organization for Next-Generation Cyber Infrastructure