OMNI Meetup#6

Software-Defined Beyond 5G in UTokyo

Ping Du

Nakao Lab, The University of Tokyo, Japan

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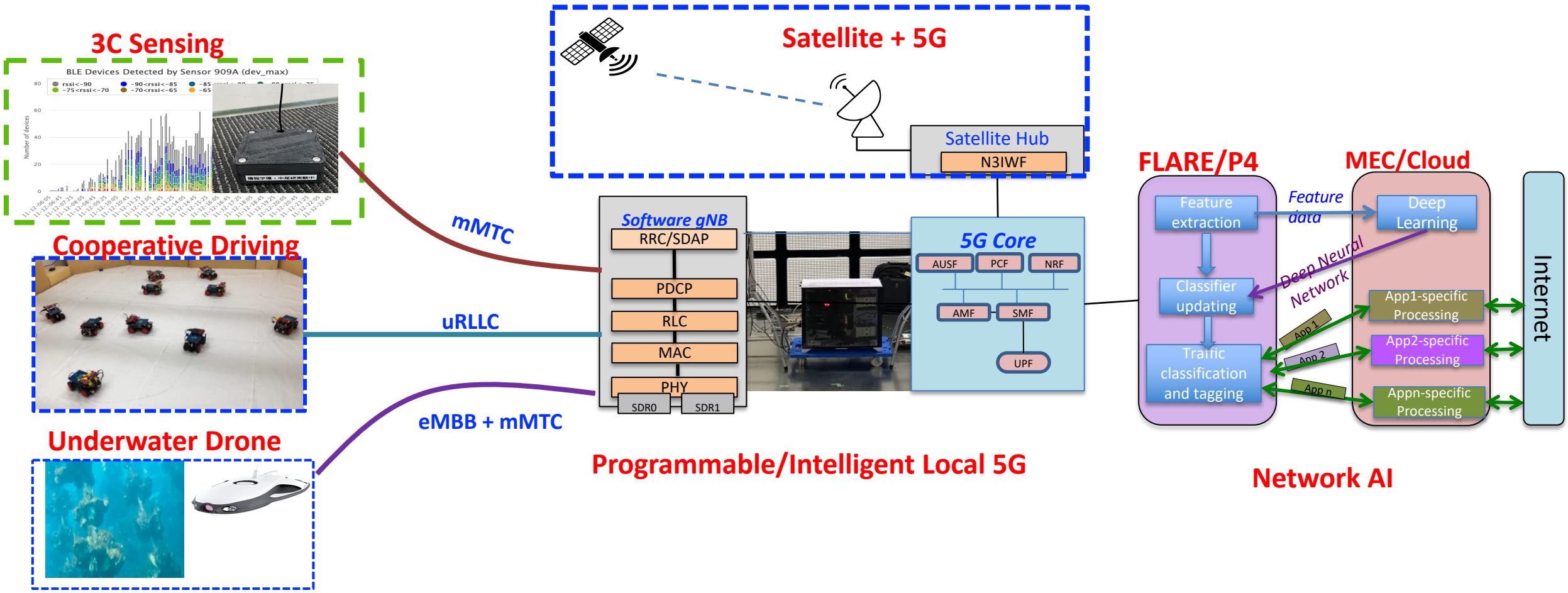
About Me

- Ping Du
  - Project Associate Professor in The University of Tokyo
  - Chief Scientist in FLARE SYSTEMS inc.
  - Heavy user of OAI and Free5GC

- Research Areas:
  - Mobile Network (5G/Beyond 5G)
  - Internet-of-Things (IoT)
  - Machine Learning

Beyond 5G Mobile Projects in NakaoLab (Birds' Eye View)



Research Projects:

- Softwarization and Customization of Local5G Box
- Applications of Local5G： 3C Sensing, Cooperative Driving, Underwater Drone
- Local 5G network optimization utilizing AI

Why do we need Local 5G?

- Advantages compared to Public 5G
  - Public 5G construction takes time, and local 5G construction can be quickly put into application.
  - Local 5G is more secure, all data transmission can be done locally.
  - It can be application-specific customization to add new network functions, while the traditional Public 5G is closed and cannot be modified
- Possible Application Scenarios

Offshore oil field

Mine

Factory Automation

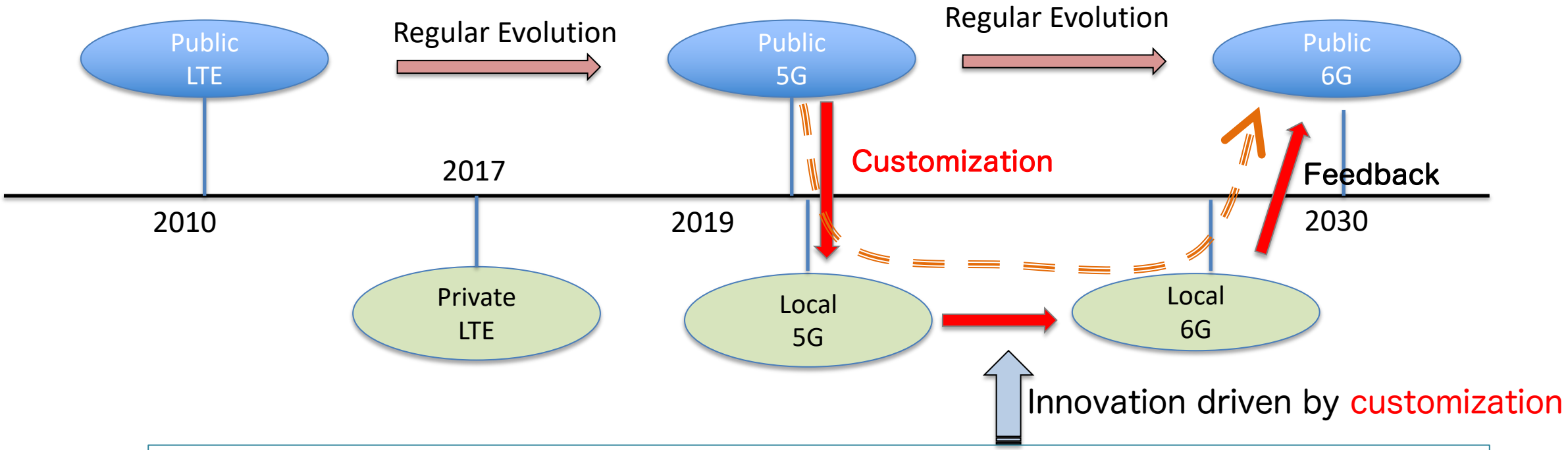
Farm

Hospital

Government

Importance of Local 5G in Academic

（Local 5G is an important step towards 6G in evolution）



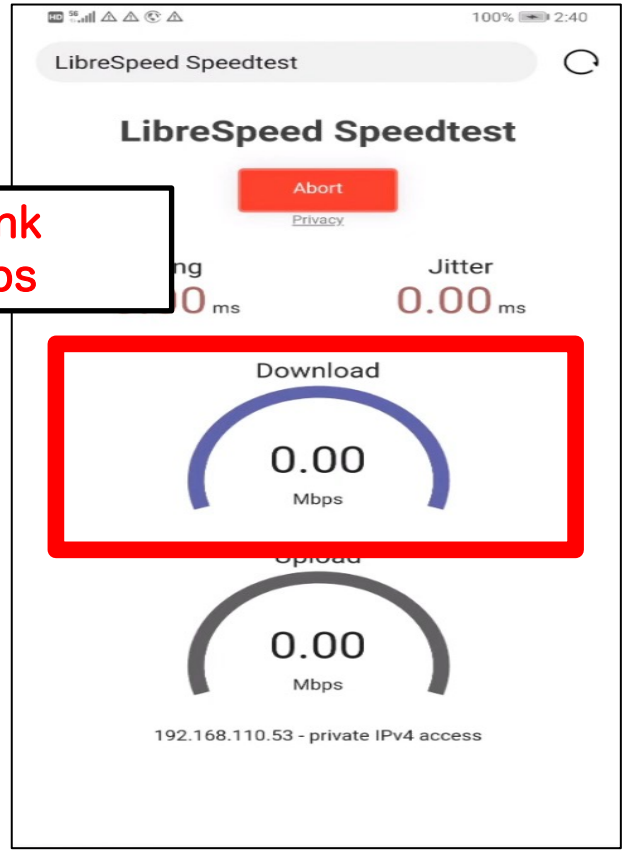
- Software-defined 5G Network
- 5G Applications：Remote Control, Cooperative Driving, Internet-of-Things (IoT)
- Intelligent Network
- Edge Computing
- Others：Local5G Federation, Satellite+Local5G Communication etc.

Software-defined Local5G Box

Software Local5G Box

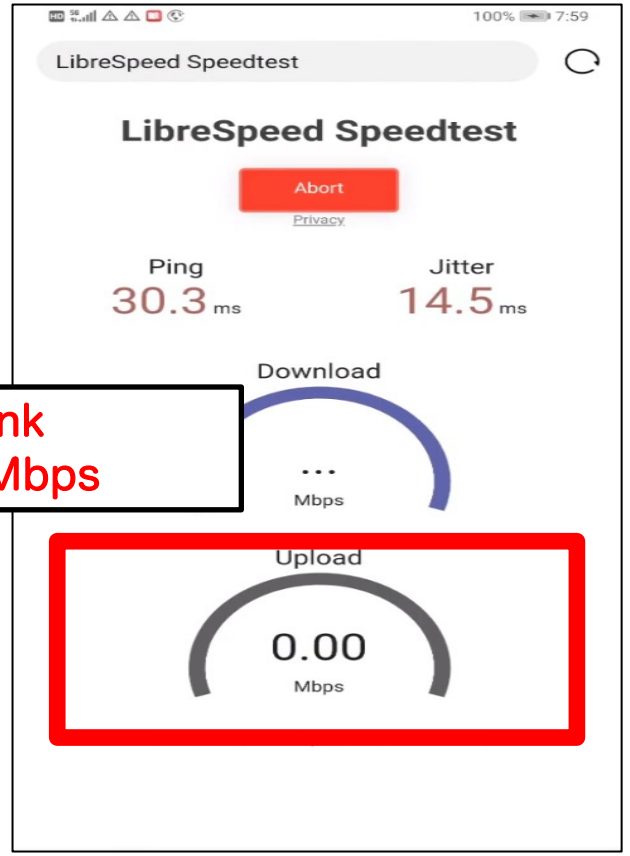
Downlink Optimization

DownLink
543Mbps



Uplink Optimization

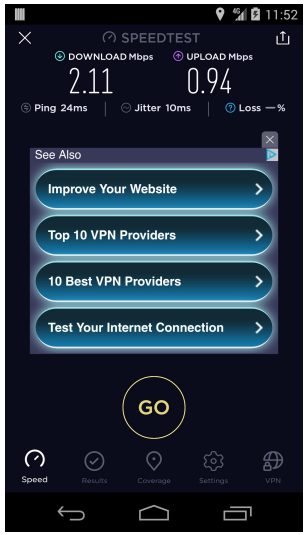
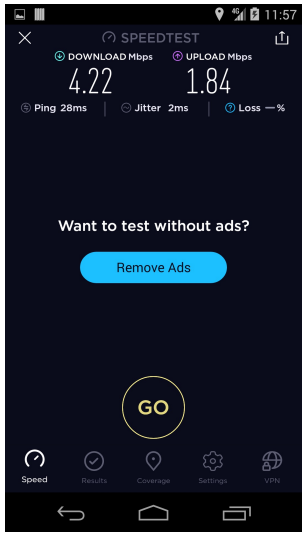
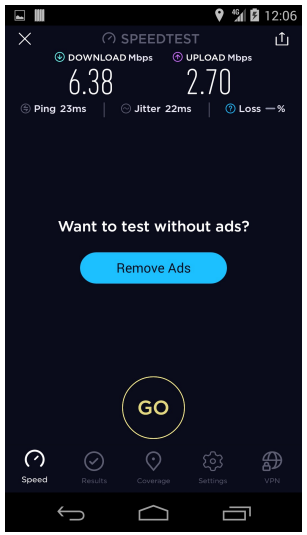
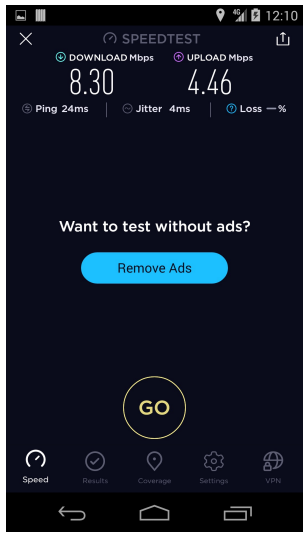
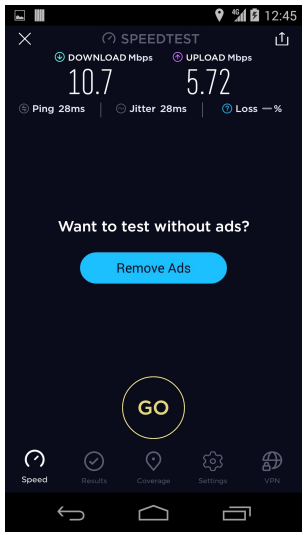
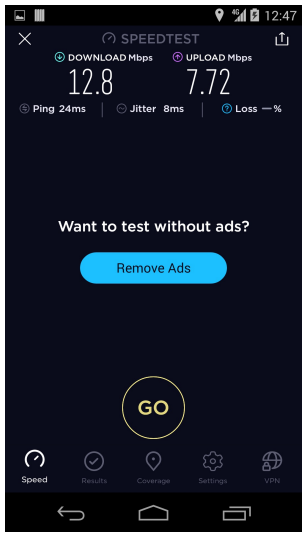
UpLink
207Mbps



Merits of Software-defined Local5G box:

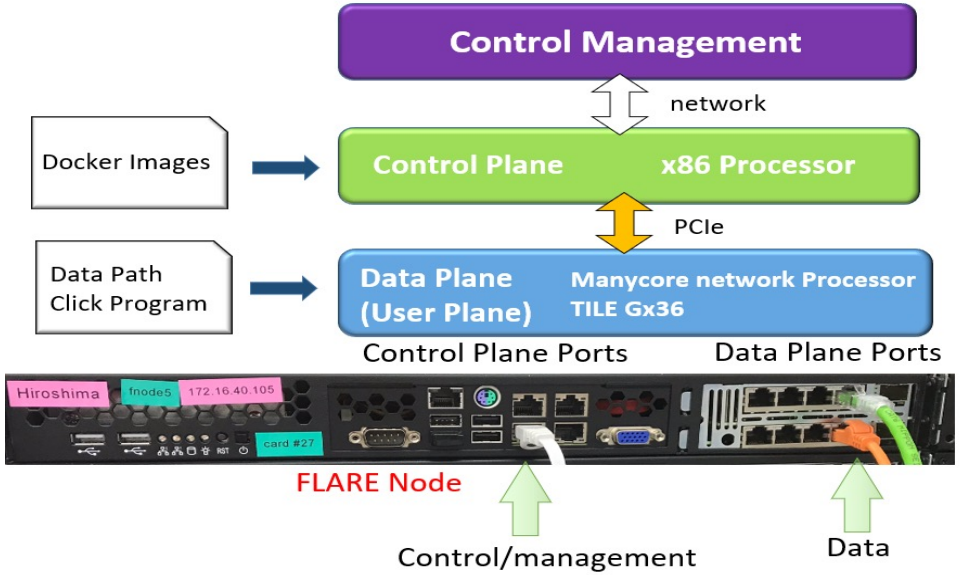
- Low-Cost: Software Local5G base station costs 10% of hardware base station
- Customization: Applications such as video streaming require more Uplink bandwidth

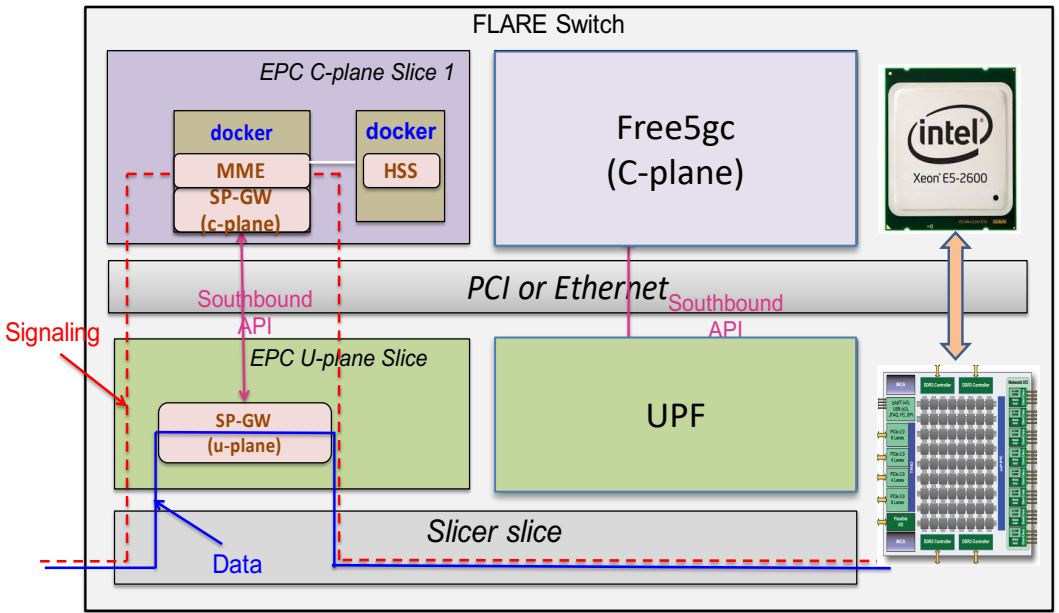
Application-specific RAN Slicing

3 RBs	6 RBs	9 RBs	12 RBs	15 RBs	18 RBs
					
DL: 2.11Mbps UL: 0.94Mbps	DL: 4.22Mbps UL: 1.84Mbps	DL: 6.38Mbps UL: 2.70Mbps	DL: 8.30Mbps UL: 4.36Mbps	DL: 10.7Mbps UL: 5.72Mbps	DL: 12.8Mbps UL: 7.72Mbps

- Proposed application-specific wireless spectrum slicing scheme based on deep learning.
- Refined the granularity of 3GPP RAN slicing from per-User to per-Packet.
- Reference work:
  - Ping Du and Akihiro Nakao, "Towards Application Specific RAN Slicing Through In-Network Deep Learning", Society Conference of IEICE, BS-7-6, 2018 (ICM English Session Encouragement Award) .

Application-Specific 5GCore on Many-Core Processors





FLARE Node

- Multi-core processors are responsible for the data plane
- The x86 processor is responsible for the control plane
- Equipped with 2 10G ports and 8 1G ports
- Multiple virtual switches installed in one FLARE chassis
- Each virtual switch operates as a switch with a different protocol

Local 5G Core

- High-performance data plane and highly flexible control plane
- User data forwarding and processing is implemented in multi-core processors.
- Signaling related components are implemented in Intel CPU

- Akihiro Nakao, Ping Du, Yoshiaki Kiriha, Fabrizio Granelli, Anteneh Atumo Gebremariam,Tarik Taleb, and Miloud Bagaa, “End-to-end network slicing for 5G mobile networks,” IPSJ Journal of information Processing., vol. 25, pp. 153–163, 2017.

Private/Local 5G Network Solution

- FLARE SYSTEMS, a startup established by the University of Tokyo based on the result of research and development, has launched a software gNB for local 5G PoC in July 2021.
- In this prototype, gNB and 5GC are implemented in a general-purpose server that runs on Linux OS.
- FW-L5G-1 provides gNB functions accompanied with compact 5G Core nodes including AMF, AUSF, SMF, and UPF, which enables network operators to easily deploy their 5G private network in a variety of fields.

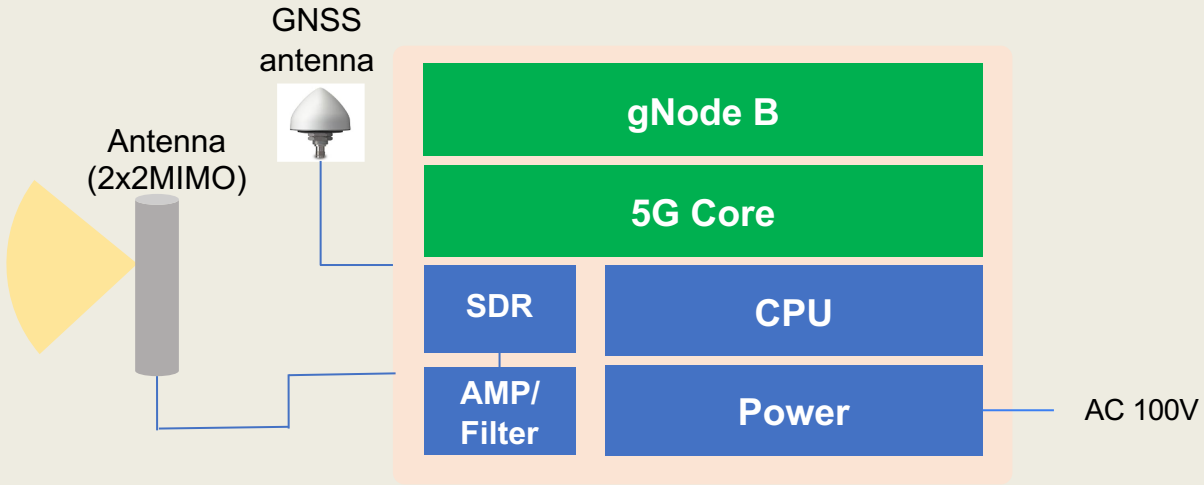


Fig.1 High level illustration of FW-L5G-1.

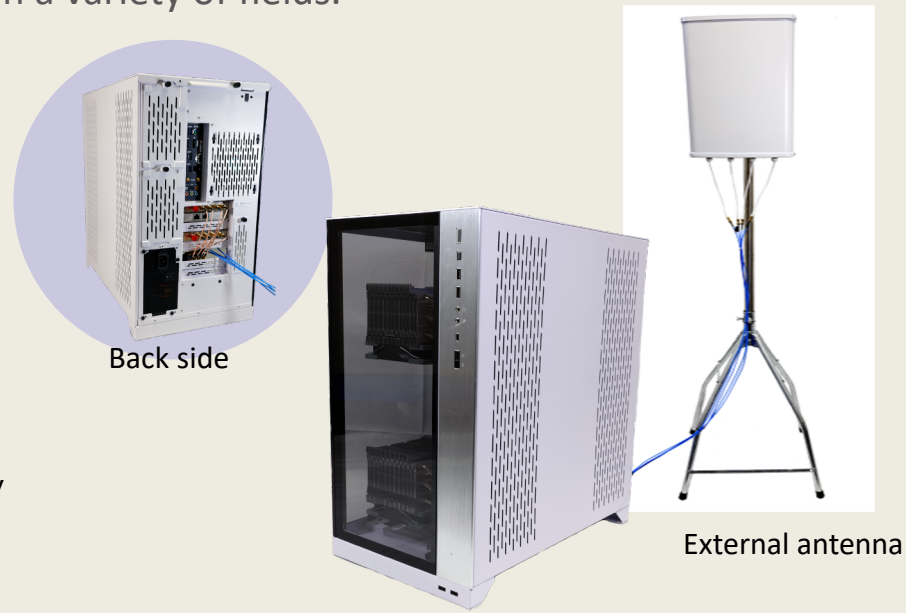


Fig.2 Appearance of FW-L5G-1.

Private/Local 5G Network Solution

- Achieved throughput 295.3 Mbps in Uplink and 182.3Mbps in Downlink (UL:DL = 7:2) on asynchronous operation at Sub-6 NR band standalone configuration. TDD pattern is easily customizable and changeable depending on various use cases.
- Compliant with 3GPP, interoperable with a variety of 5G devices.
- Available both internal and external 5G Core, interoperable with the free5GC, an open-source project for 5G mobile core networks.
- Participated in Local 5G National Project organized by Ministry of Internal Affairs and Communications, performed at Edajima testbed for remote monitoring in the aquaculture industry in Hiroshima in 2020, and used for Fujisan DX Project in 2021.

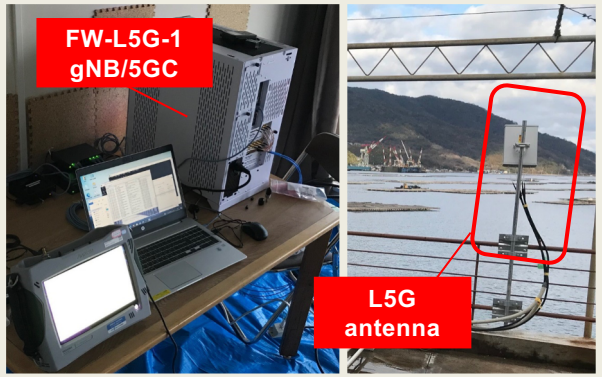


Fig.5 FW-L5G-1 at Edajima testbed.

Fig.3 TDD patterning demo in Lab.

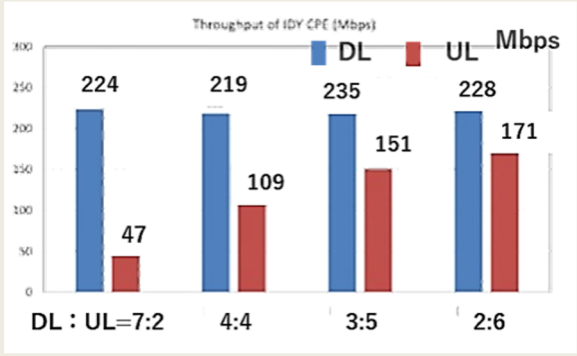


Fig.4 Throughput performance in FW-L5G-1.

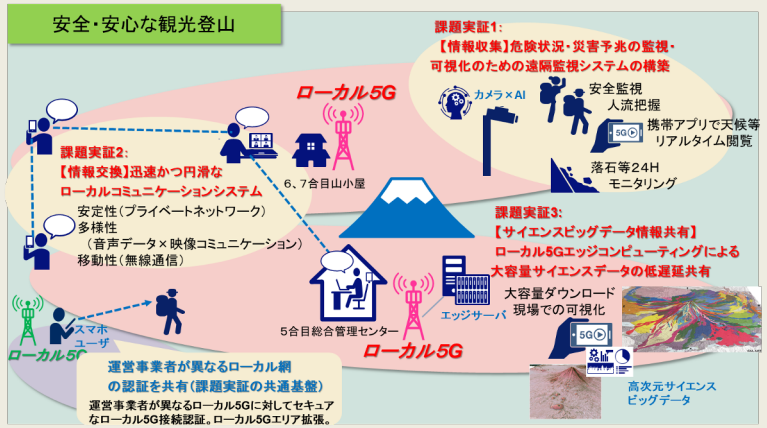
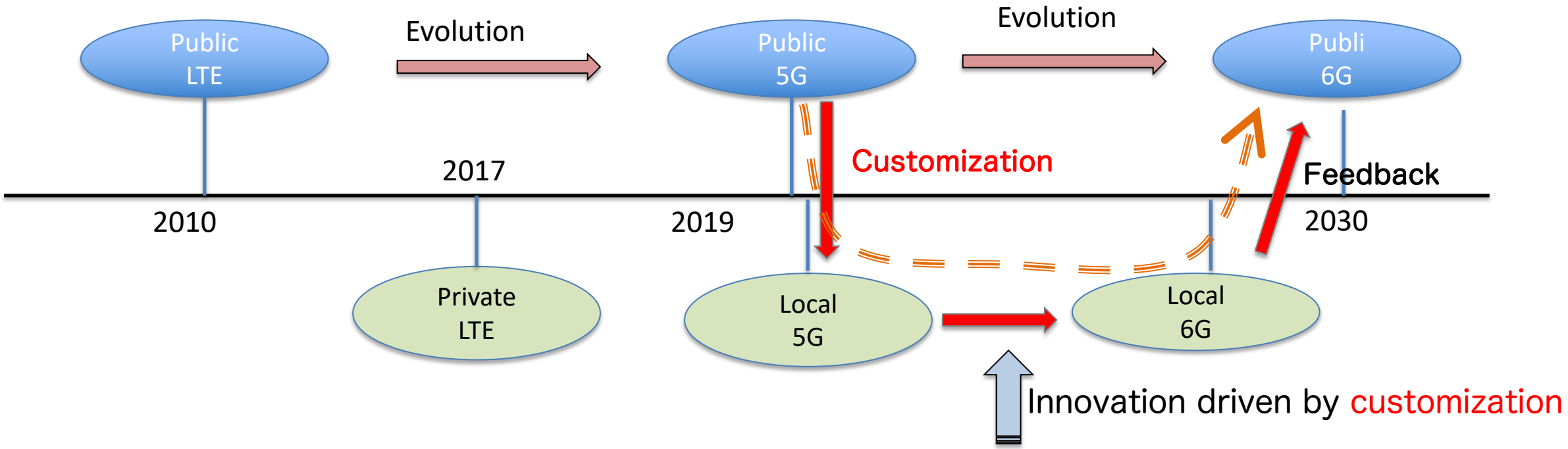


Fig.6 Fujisan DX Project .

Importance of Local 5G in Academic

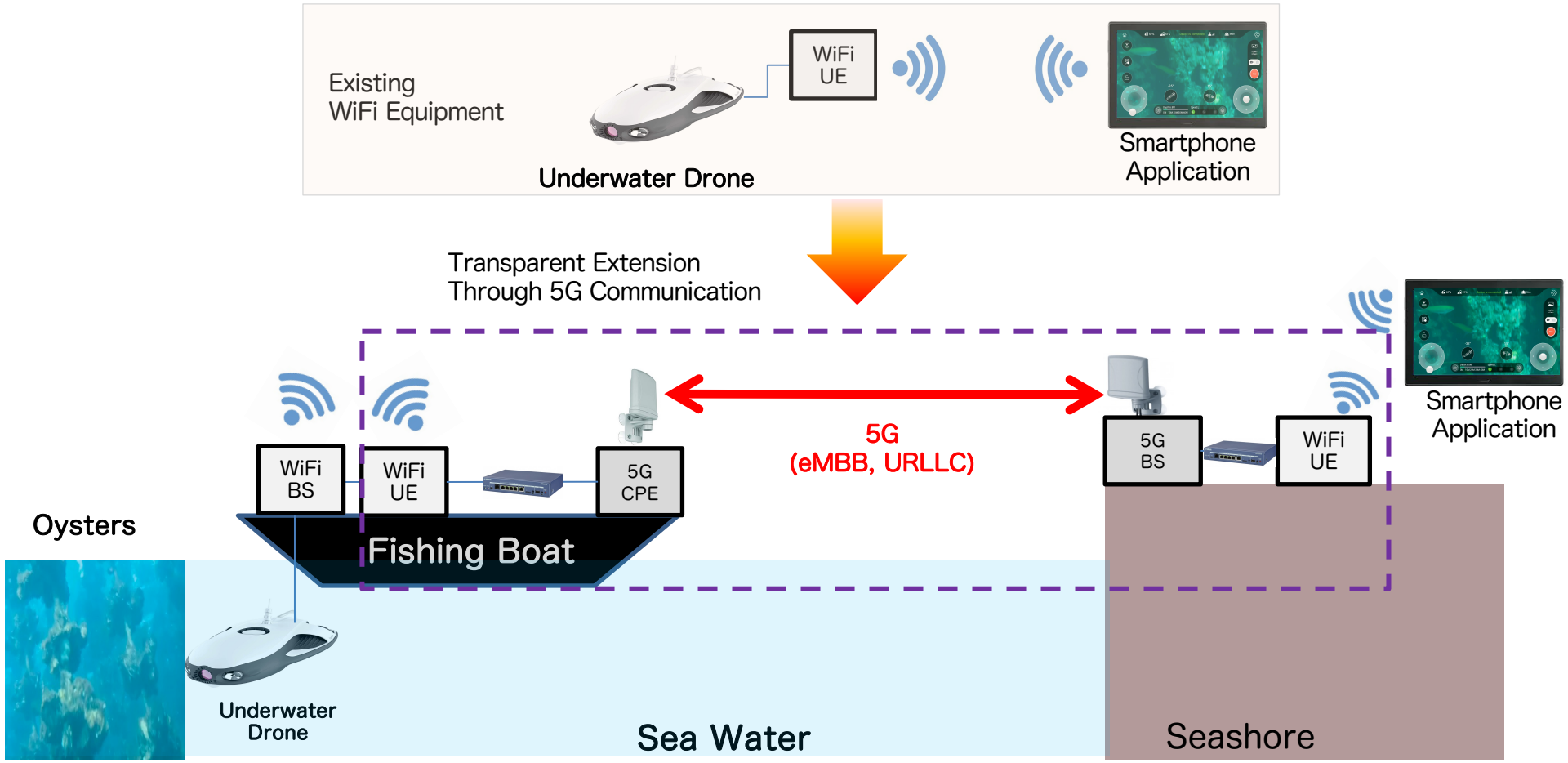
（Local 5G is an important part towards 6G in evolution）



- Software-defined 5G Network
- 5G Applications：Remote Control，Cooperative Driving，Internet-of-Things (IoT)
- Intelligent Network
- Edge Computing
- Others：Local5G Federation，Satellite+Local5G Communication etc.

5G Transparent Extension of Control Range of WiFi equipment (underwater drone)

(Joint project with Docomo)

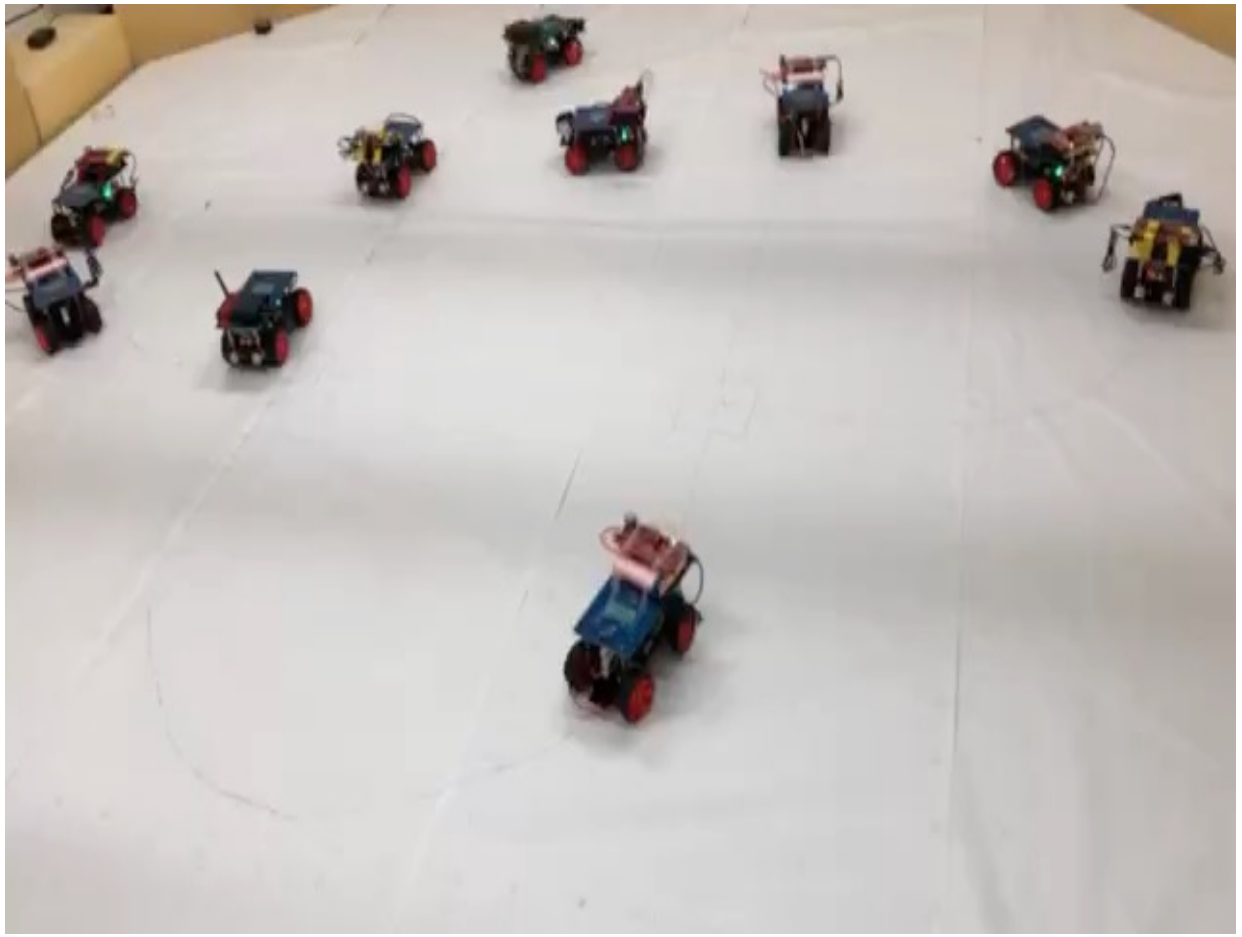


- 甄　宇杰, 杜　平, 中尾彰宏, 外園悠貴, 南田智昭, 油川雄司, "5G超低遅延通信と大容量通信を利用する遠隔監視システムの構築", IEICE, NS2020-3, 2020.
- 外園悠貴, 南田智昭, 油川雄司, 杜　平, 中尾彰宏, "5Gにおける28GHz帯を用いた水中ドローン遠隔制御実験", IEICE, NS2020-3, 2020.

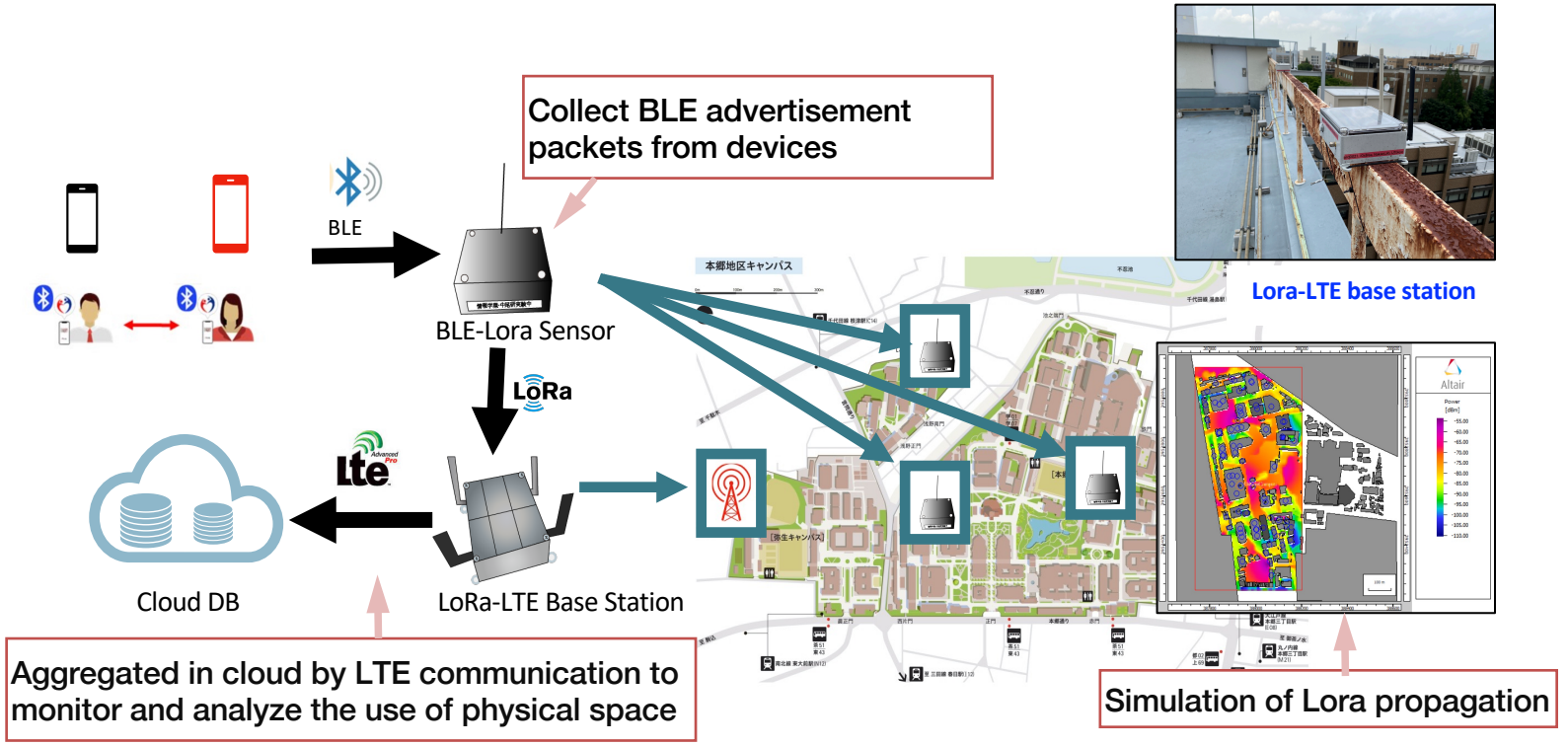
5G Live Videso Streaming and Realitime Control of Under-Water Drone

Cooperative Driving

(Docomo Openhouse 2020)



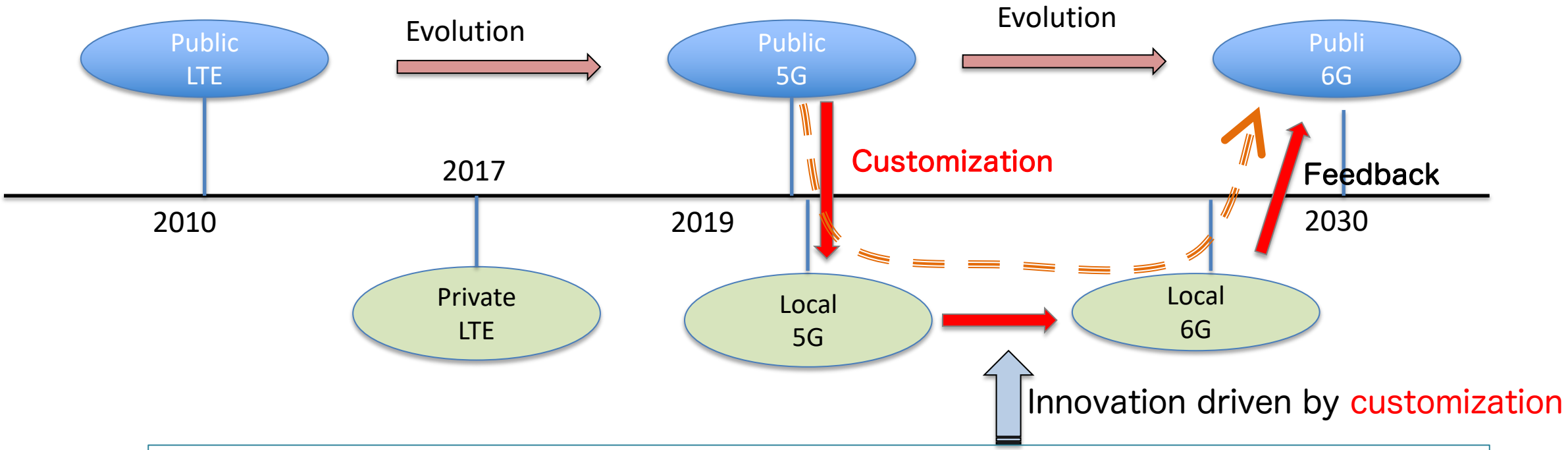
Real-time Detection of Population Density



- A large-scale monitoring system based on hundreds of low-power long-range radio (Lora) and Bluetooth (BLE) sensors was deployed across four campuses of the University of Tokyo.
- Infer and predict population density with machine learning
- Provide students and school leaders with real-time campus population densities to avoid densities and reduce the spread of COVID-19.

Importance of Local 5G in Academic

（Local 5G is an important part towards 6G in evolution）



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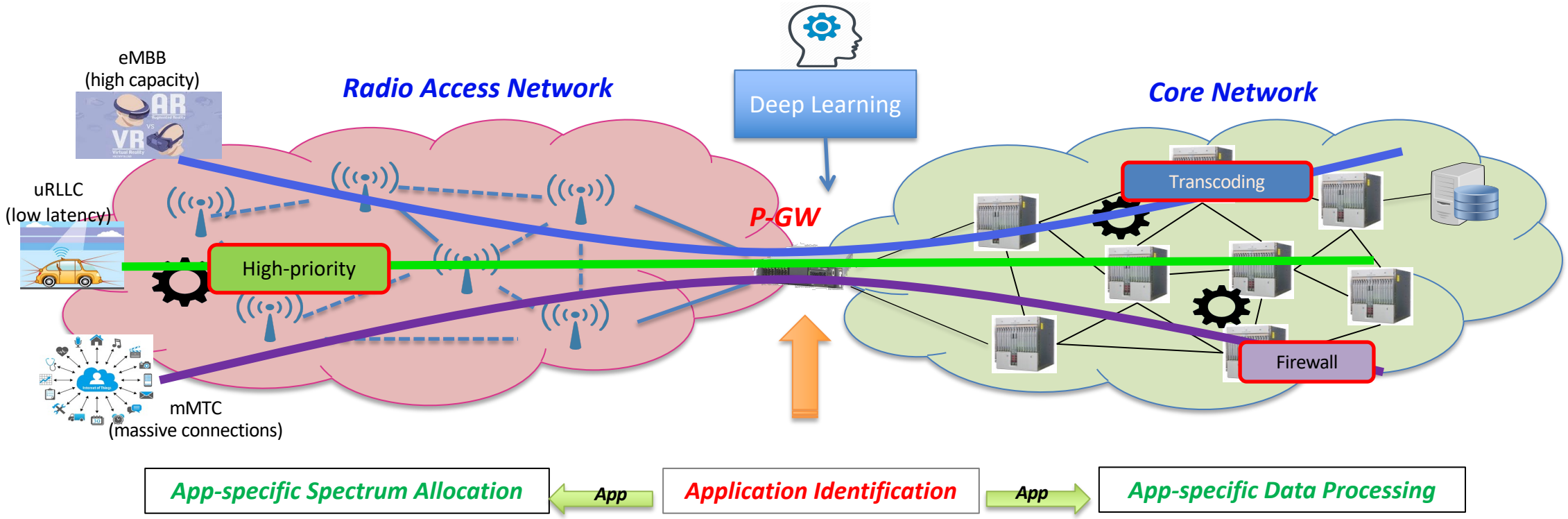
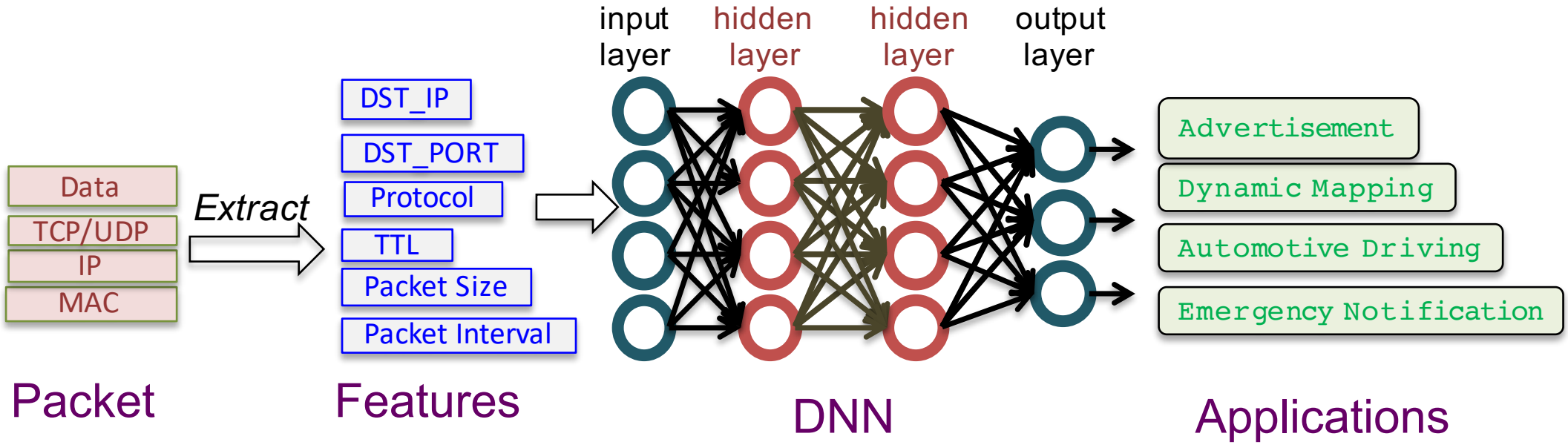
Deep-learning based 5G Mobile Network



- P-GW is the best point to perform application identification since all traffic needs to go through it.
- P-GW can convey its identified app-info to both RAN and CN.

AI Utilization in Network Communication Area

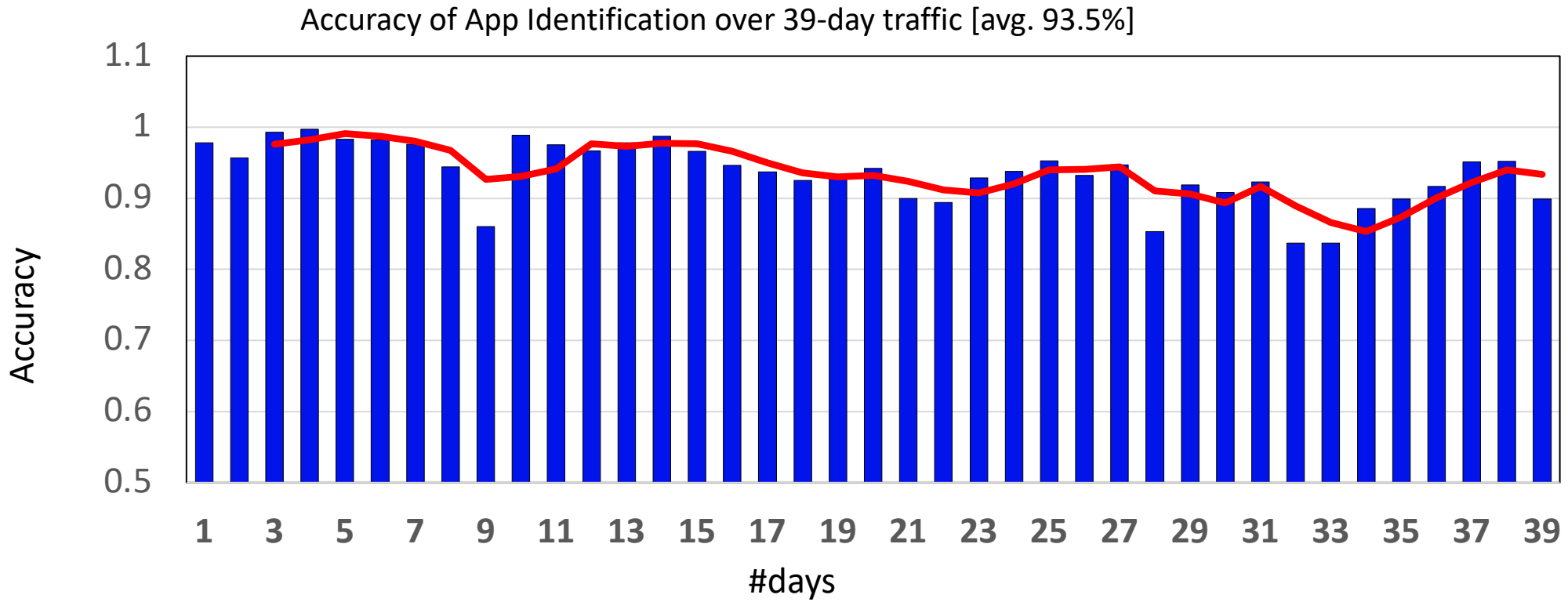


- Extract features from packet headers, without invading user privacy
- The feature is learning using deep neural network (DNN)
- Output is application identification

- Related work
  - ITU AI /ML 5G Challenge (Dec, 2020)
    - Best Performance Award Global Round in Japan, Bronze Champion (3rd prize) in Final Conference
  - Ping Du, Akihiro Nakao, Zhaoxia Sun, Lei Zhong and Ryokichi Onishi, “Deep Learning-based C/U Plane Separation Architecture for Automotive Edge Computing”, The Fourth ACM/IEEE Symposium on Edge Computing (SEC), 2019.

Preliminary experimental results

Features: <dst_ip, dst_port, protocol, ttl, packet_size of first 5 packets>
DNN: 8-layer (Input-layer, 6 Hidden-layer, Output-layer)
Training data: 14-days
Applications: 200 popular mobile applications
Accuracy: average 93.5%



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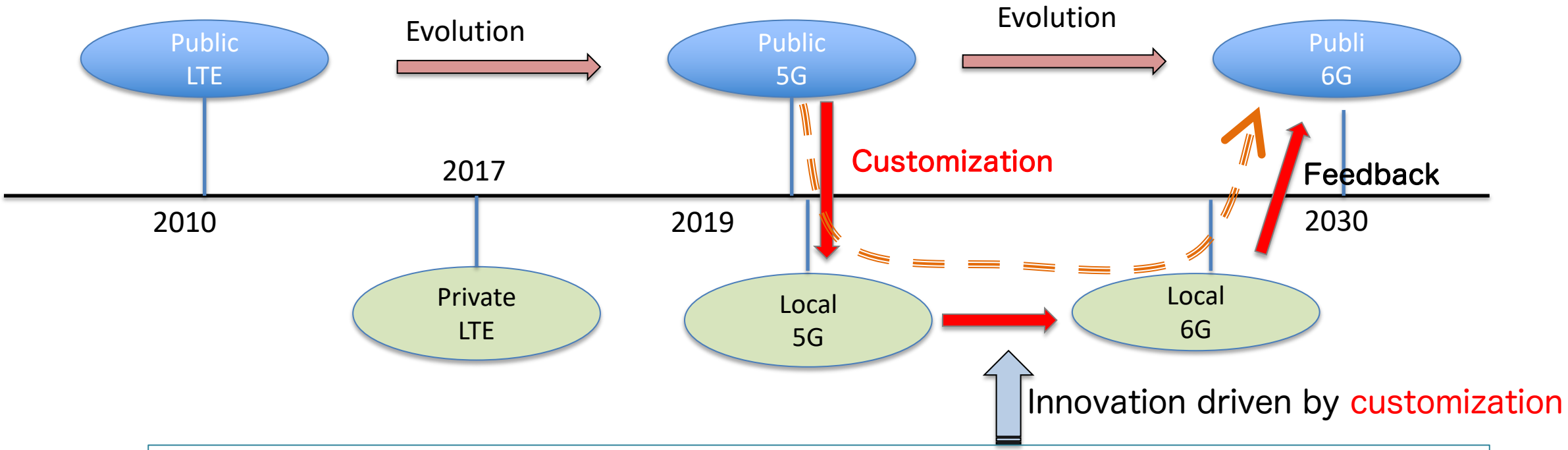

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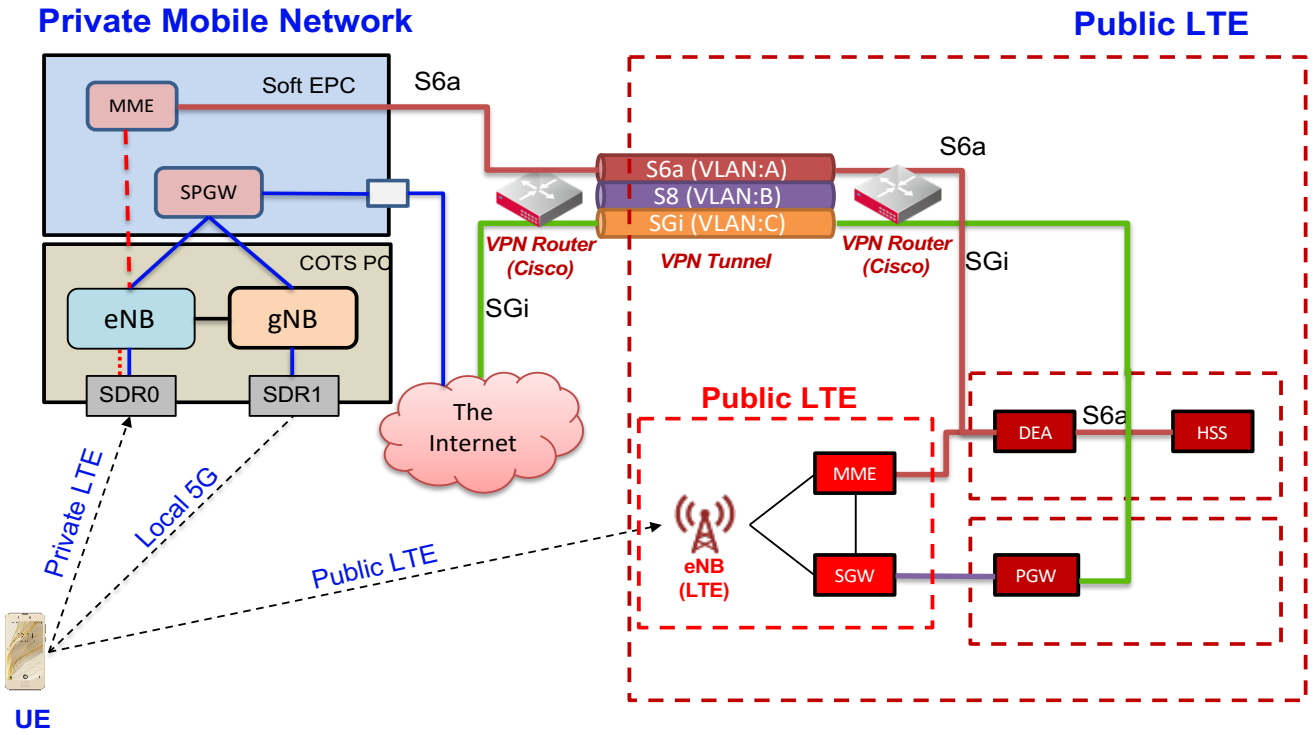
Integration of Local 5G and Public LTE/5G



- Conventional Local 5G has limited access coverage with a single SIM, and multiple SIM compatible terminals and SIM management impose a burden on users

- UE preferentially connects to Local 5G lines on the University of Tokyo campus (zero cost, ultra-low latency, high reliability)
- Connect to Public LTE/5G lines outside of Local 5G (wide area)

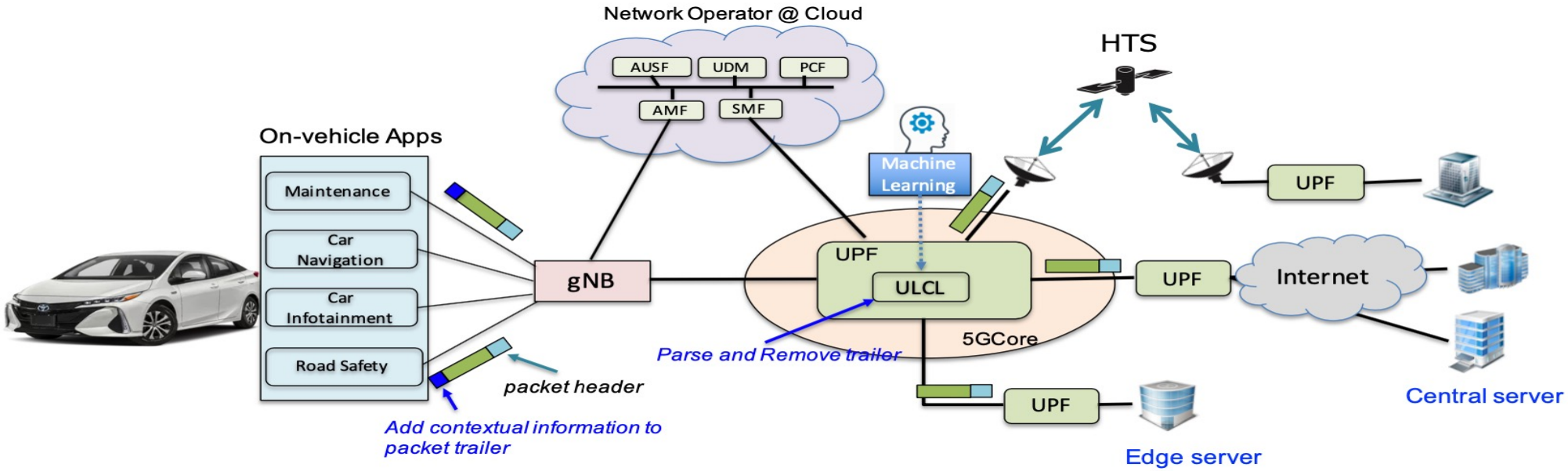
Related work:

Ping Du, Aerman Tuerxun, Anan Sawabe, Takanori Iwai, Akihiro Nakao, “Automatic Check-In Service at Businesses Enabled with Private Mobile Networks”, IEEE Global Communications Conference (Globecom), 2020.

Edge Computing

(Joint project with Toyota)

- Problems
  - There are multiple on-vehicle apps that need to be classified and sent to different 3rd-party servers for application-specific processing
  - Conventional APN-based classification is not flexible for an increasing number of applications.
- Proposal
  - We propose and prototype ULCL (uplink classifier) network functions as a UPF function installed from SMF.

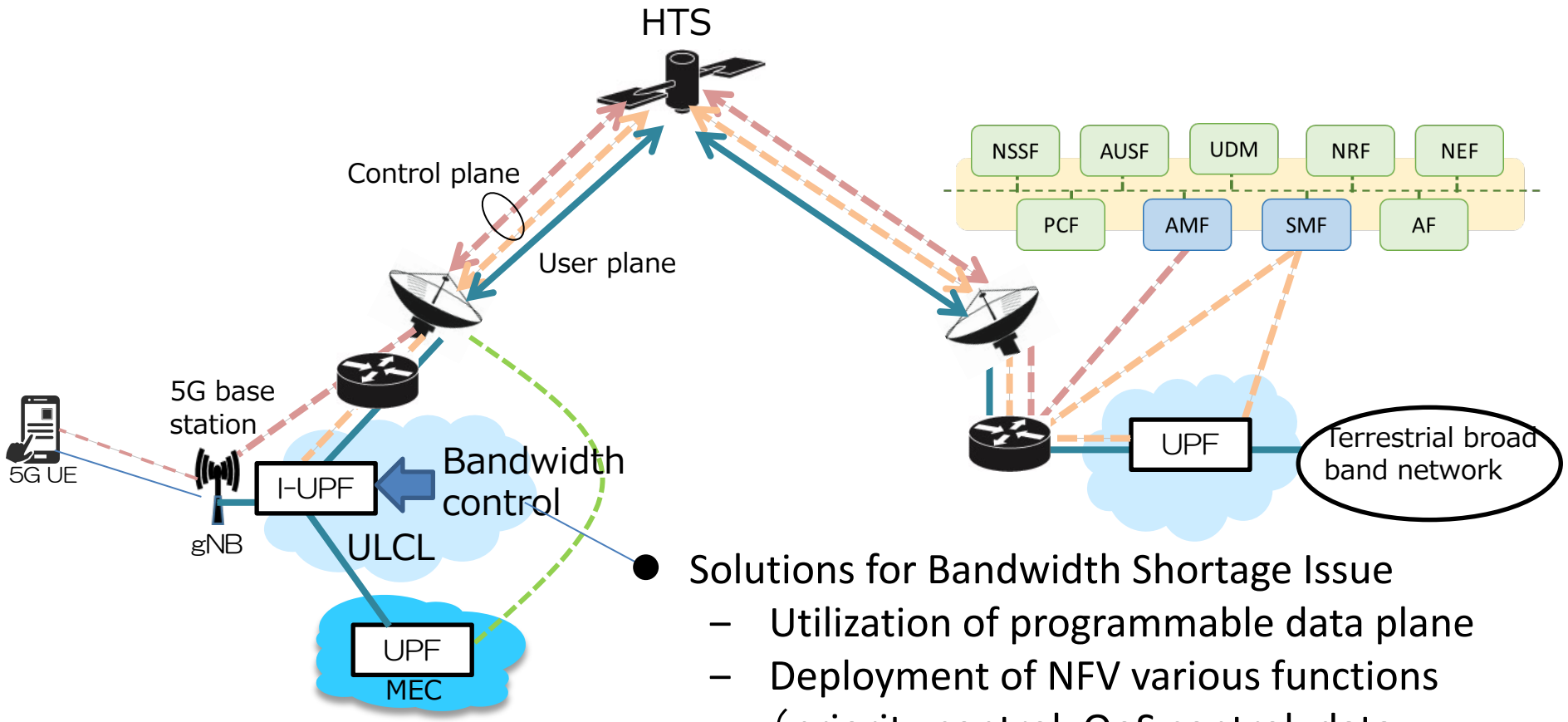


Related paper:

Ping Du, Akihiro Nakao, Lei Zhong , Jing Ma and Ryokichi Onishi, "Service-aware 5G/B5G Cellular Networks for Future Connected Vehicles", IEEE International Smart Cities Conference (ISC2), 2021.

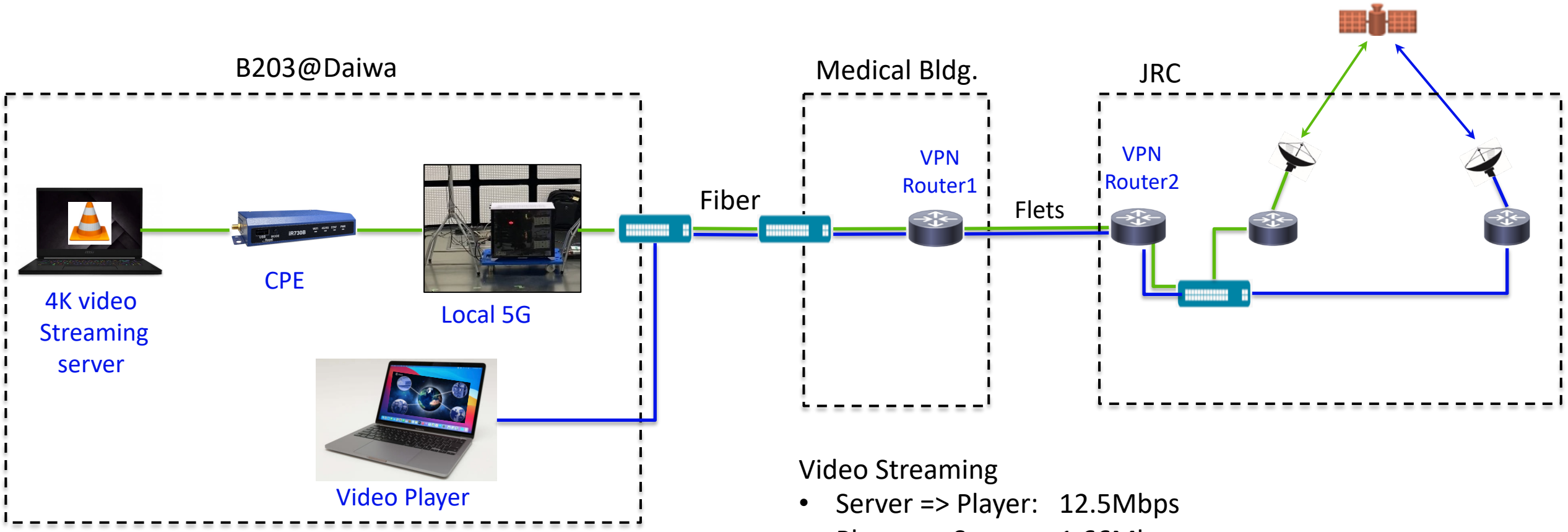
R&D of Ka-band Satellite Communication Control for Various Use Cases 2020-2025

NICT & UTokyo



- Solutions for Delay Issue
  - Edge computing
  - Cache
  - Function distribution
- Solutions for Bandwidth Shortage Issue
  - Utilization of programmable data plane
  - Deployment of NFV various functions （priority control, QoS control, data compression, protocol conversion）
  - Network slicing

Network Setting of Satellite+5G



Video Streaming
- Server => Player: 12.5Mbps
- Player => Server: 1.66Mbps

RTT: 615/645/676/27.5 (min/avg/max/stddev)

Video Streaming 4K video

Summary

- Local 5G will open a door to the innovations towards 6G.
- We have introduced the innovation activities in Local 5G /B5G in UTokyo, including:

  - Software-defined 5G Network
  - 5G Applications：Remote Control，Cooperative Driving，Internet-of-Things (IoT)
  - Intelligent Network
  - Edge Computing
  - Others：Local5G Federation，Satellite+Local5G Communication etc.

- Looking forward to cooperation with OMNI community