CloudEdge Fusion

CloudEdge Fusion Project

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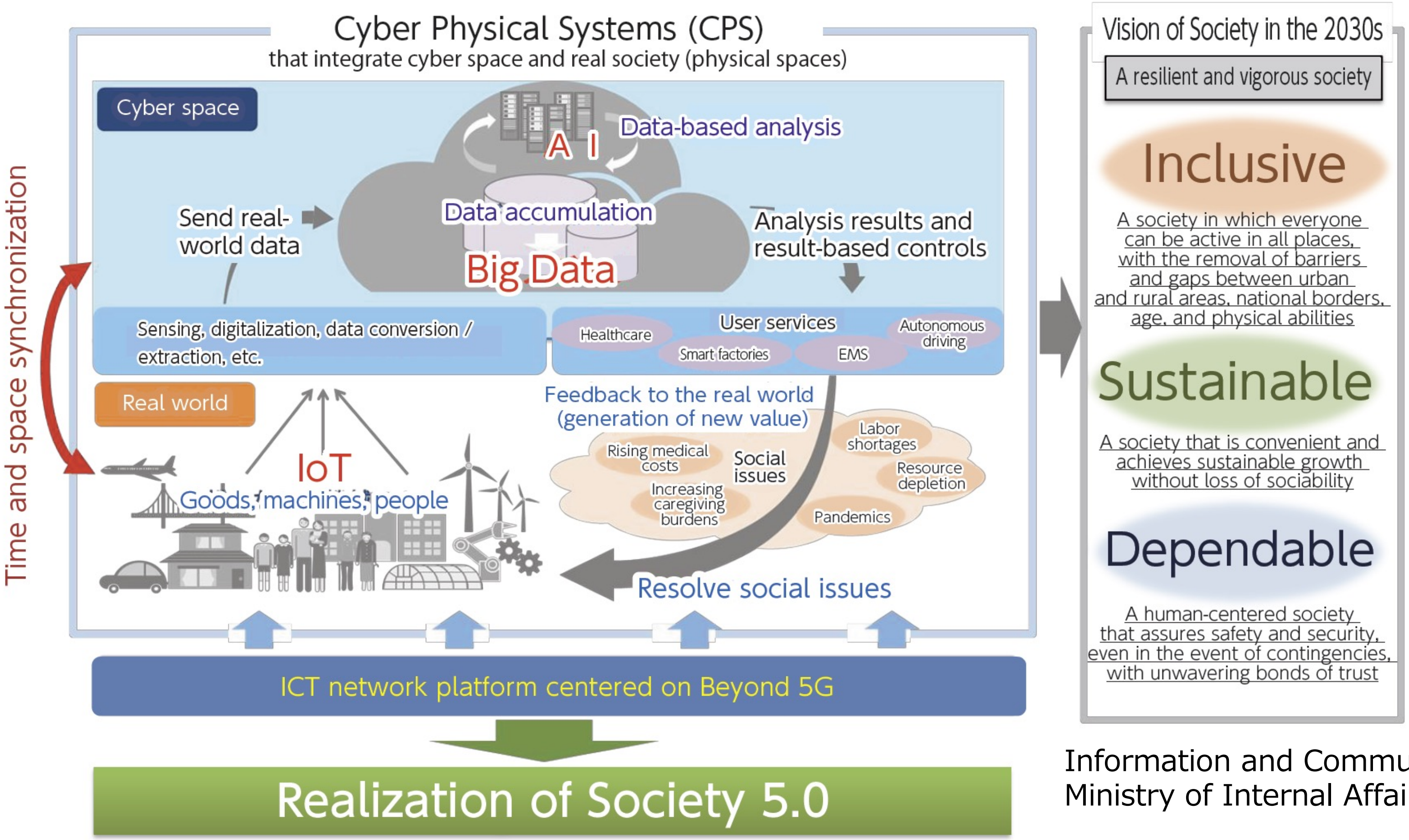
Cyber Physical Systems / Society 5.0

Figure 4-1-1-1 Vision of society expected in the 2030s



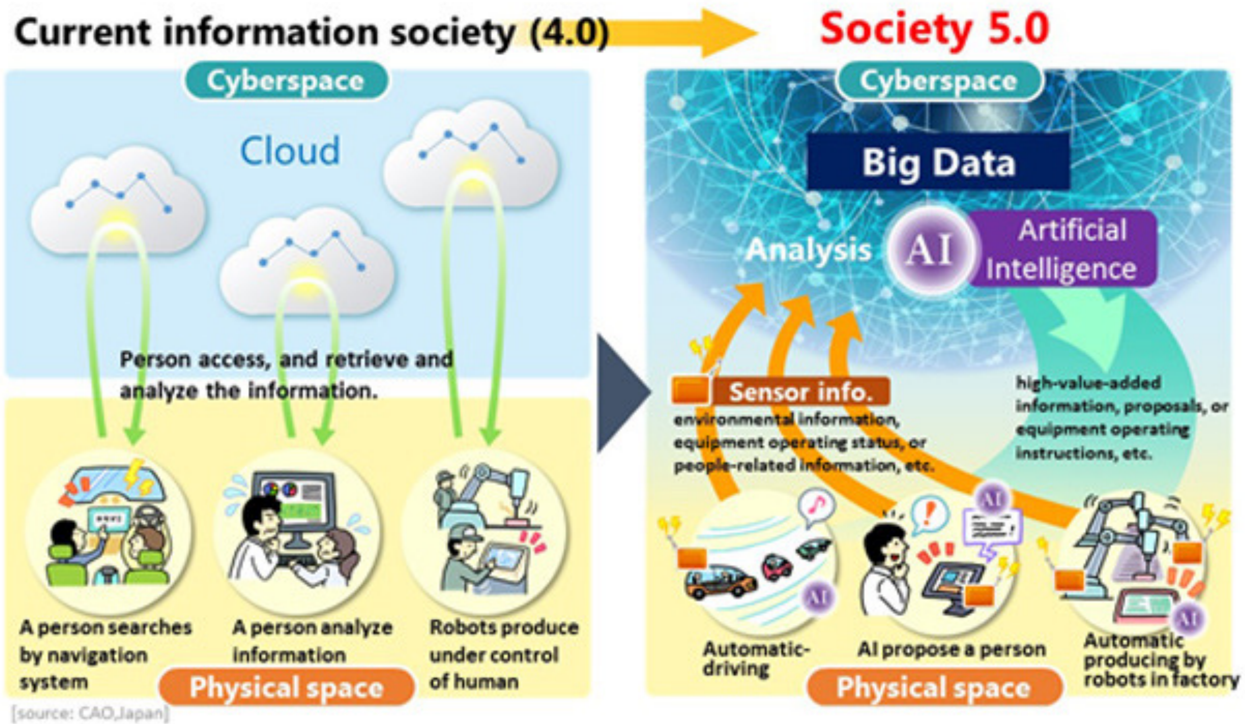
In the 2030s, cyber space and physical spaces will become even more tightly integrated.

Moreover, a resilient and vigorous society will emerge in which cyber space not only extends the functions of physical spaces but also maintains the smooth functioning of people's lives and economic activities even when contingencies occur in physical spaces

Information and Communications in Japan 2020 white paper
Ministry of Internal Affairs and Communications, Japan

How Society 5.0 works

- A huge amount of information from sensors (Real world data; RWD) in physical space is accumulated in cyberspace.
- In cyberspace, analysis results are fed back to humans in physical space in various forms.
- Different applications have different requirements for analysis processing capacity, latency, etc.



Source: https://www8.cao.go.jp/cstp/society5_0/

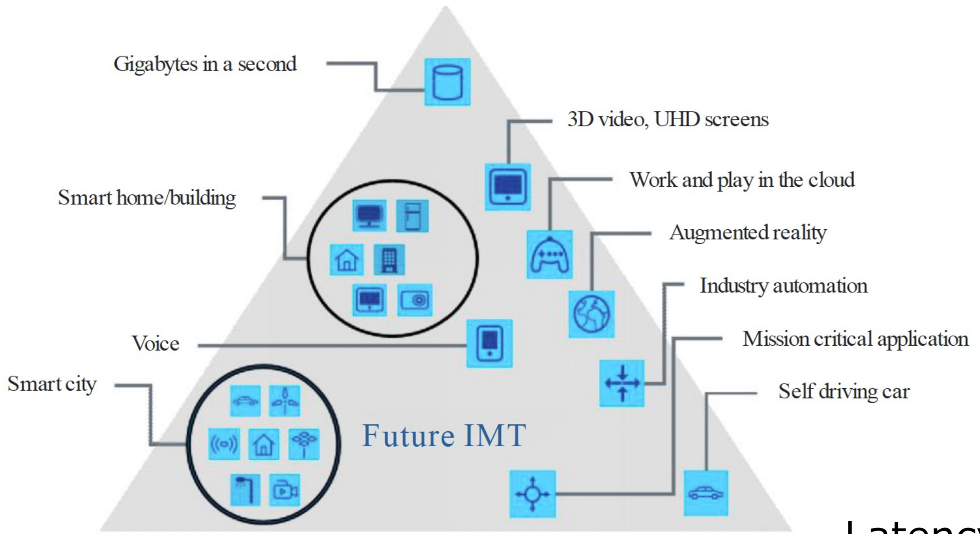
CPS and IT infrastructure

- In some applications, data from the physical world (Real World Data: RWD) must be processed within a certain time frame
  - Autonomous driving
  - Factory control
  - VR/AR
- Requirements for IT infrastructure
  - Reliable low-latency processing
  - Can process data from a huge number of IoT devices
  - Processing and communication throughput
  - Security and privacy

5G/Post-5G Communication

Anticipated Post-5G technologies promise to simultaneously provide low latency and high reliability, massive connections, large capacity, and security.

Enhanced mobile broadband (eMBB)



Latency <= 1ms (wireless section)

Massive machine type communications (mMTC)

Ultra-reliable and low latency communications (URLCC)

Recommendation ITU-R M.2083-0

All we need is 5G/P5G ?

- Cyberspace is enabled by networking and computing
- In addition to wireless networks, wired networks and computing must be able to achieve:
  - Low latency
  - High reliability
  - Support a huge number of connections
  - Security.
- Edge computing at the network edge is one solution, but···
  - Computational resources at the network edge are small, so statistical multiplexing effects cannot be expected
    - Lower utilization, higher cost (CAPEX, OPEX)
  - Difficulties in sharing data in wide-area.

Low latency and availability required for 5G/post-5G use cases

TABLE IV: The summary of 5G requirements for CAV use cases [3], [4], [49], [80]–[87].

	Use case	Latency (ms)	Reliability	Availability (%)	Device density	Traffic density	User throughput	Mobility (km/h)
Smart Factory [3], [4]	Manufacturing cell [3]	5	10^{-9}	> 99.9999	0.33-3/m^2	N/S[2]	N/S	<30
	Machine tools [3]	0.5	10^{-9}	> 99.9999	0.33-3/m^2	N/S	N/S	<30
	Printing machines [3]	2	10^{-9}	> 99.9999	0.33-3/m^2	N/S	N/S	<30
	Packaging machines [3]	1	10^{-9}	> 99.9999	0.33-3/m^2	N/S	N/S	<30
	Cooperative motion control [4]	1	10^{-9}	> 99.9999	0.33-3/m^2	N/S	N/S	<30
	Video-operated remote control [4]	10-100	10^{-9}	> 99.9999	0.33-3/m^2	N/S	N/S	<30
	Assembly robots or milling machines [4]	4-8	10^{-9}	> 99.9999	0.33-3/m^2	N/S	N/S	<30
	Mobile cranes [4]	12	10^{-9}	> 99.9999	0.33-3/m^2	N/S	N/S	<30
	Process automation - Monitoring [81]	50	10^{-3}	99.9	10000/plant	10 Gbps/km^2	1 Mbps	<5
	Process automation - Remote control [81]	50	10^{-5}	99.999	1000/km^2	100 Gbps/km^2	<100 Mbps	<5
Smart Grids	Electricity distribution - Medium Voltage [81]	25	10^{-3}	99.9	1000/km^2	10 Gbps/km^2	10 Mbps	0
	Electricity distribution - High Voltage [81]	5	10^{-6}	99.9999	1000/km^2	100 Gbps/km^2	10 Mbps	0
Smart Vehicle [81]	Autonomous driving [84]	5	10^{-5}	99.999	500-3000/km^2	N/S	0.1-29 Mbps	urban < 100, highway< 500
	Collision warning [87]	10	$10^{-3} - 10^{-5}$	99.999	500-3000/km^2	N/S	0.1-29 Mbps	urban < 100, highway< 500
	High-speed train [81]	10	N/S	N/S	1000/train	12.5-25 Gbps/train	25-50 Mbps	<500
ITS [49]	Road safety urban [49]	10-100	$10^{-3} - 10^{-5}$	99.999	3000/km^2	10 Gbps/km^2	10 Mbps	<100
	Road safety highway [49]	10-100	$10^{-3} - 10^{-5}$	99.999	500/km^2	10 Gbps/km^2	10 Mbps	<500
	Urban intersection [49]	<100	10^{-5}	99.999	3000/km^2	10 Gbps/km^2	10 Mbps	<50
	Traffic efficiency [49]	<100	10^{-3}	99.9	3000/km^2	10 Gbps/km^2	10 Mbps	<500
	Traffic jam [85]	8	N/S	95.0	N/S	480 Gbps/km^2	20-100 Mbps	N/S
Smart City [85]	Large outdoor event [85]	N/S	10^{-2}	99.0	4/m^2	900 Gbps/km^2	30 Mbps	N/S
	Shopping mall [85]	N/S	10^{-2}	99.0	N/S	N/S	60-300 Mbps	N/S
	Stadium [85]	N/S	10^{-2}	99.0	4/m^2	0.1-10 Mbps/m^2	0.3-20 Mbps	N/S
	Dense urban [85]	N/S	N/S	N/S	200000/km^2	700 Gbps/km^2	60-300 Mbps	N/S
	Media on demand [85]	200-5000	TBC	95.0	4000/km^2	60 Gbps/km^2	15 Mbps	N/S

RWD applications require large capacity, many simultaneous connections, high reliability and low latency, but the requirements vary by application

Data volume, type and amount of processing required, processing time (latency) requirements, etc.

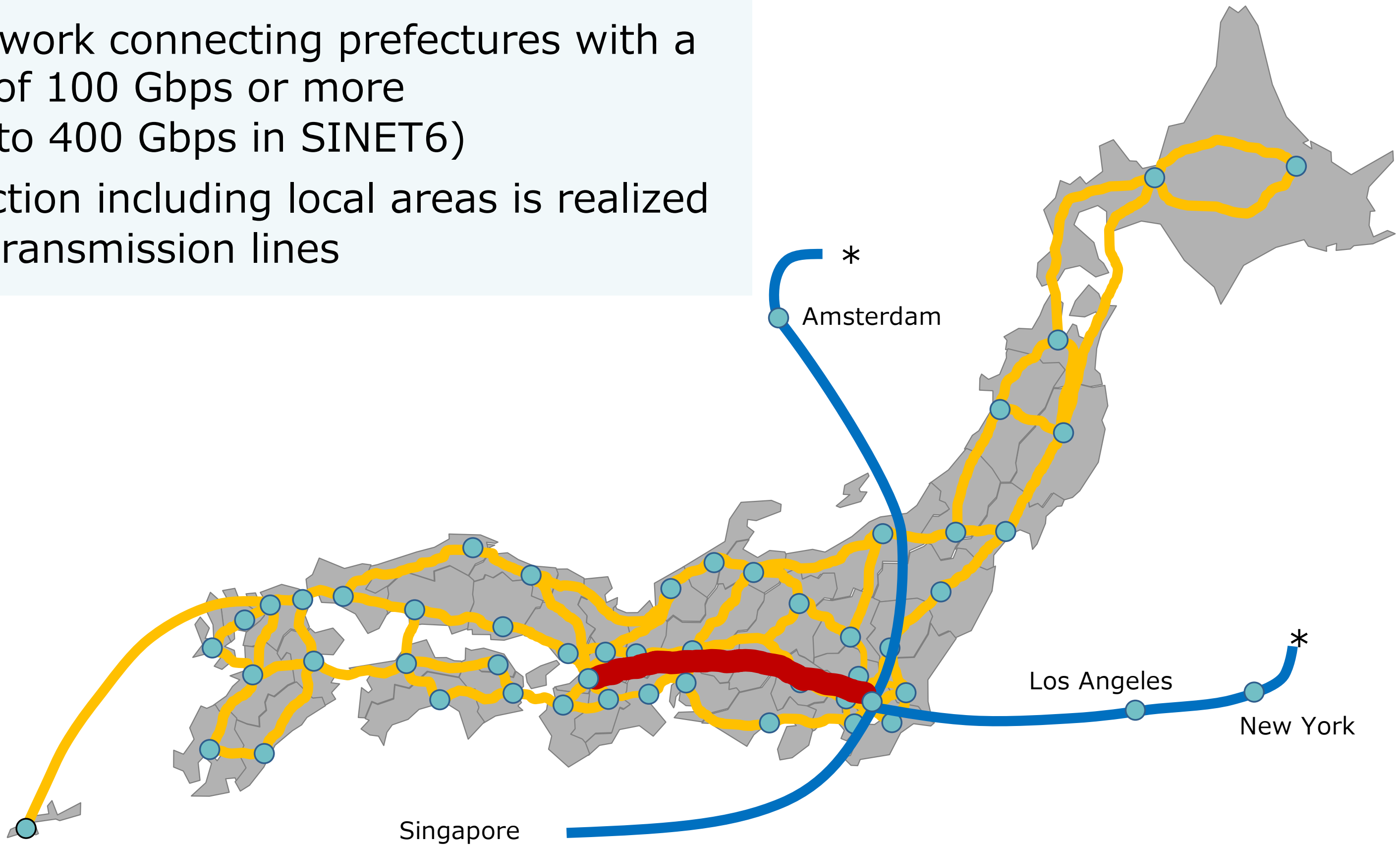
For automated driving and smart factory use cases, low latency (<100ms) and high availability (>99.9%) must be met.

(source) T.M.Ho, et. al., Next-generation Wireless Solutions for the Smart Factory, Smart Vehicles, the Smart Grid and Smart Cities, arXiv:1907.10102

How small can the latency of a wired network be?

- SINET: An academic research network operated by the National Institute of Informatics (NII)
- A mesh network connecting prefectures with a bandwidth of 100 Gbps or more (Upgraded to 400 Gbps in SINET6)
- Interconnection including local areas is realized with short transmission lines

SINET5 (～ 2022) Topology



(As of June 1, 2021)

	Participation (%)
National Universities	86 (100%)
Public Universities	90 (96%)
Private Universities	430 (70%)
Junior Colleges	84 (26%)
Technology Colleges	56 (98%)
Inter-University Research Institute Corporation	16 (100%)
Other	217
Total	**979**

Courtesy of NII

: SINET DC : Domestic line (400Gbps) : Domestic line (100Gbps) : International line (100Gbps)

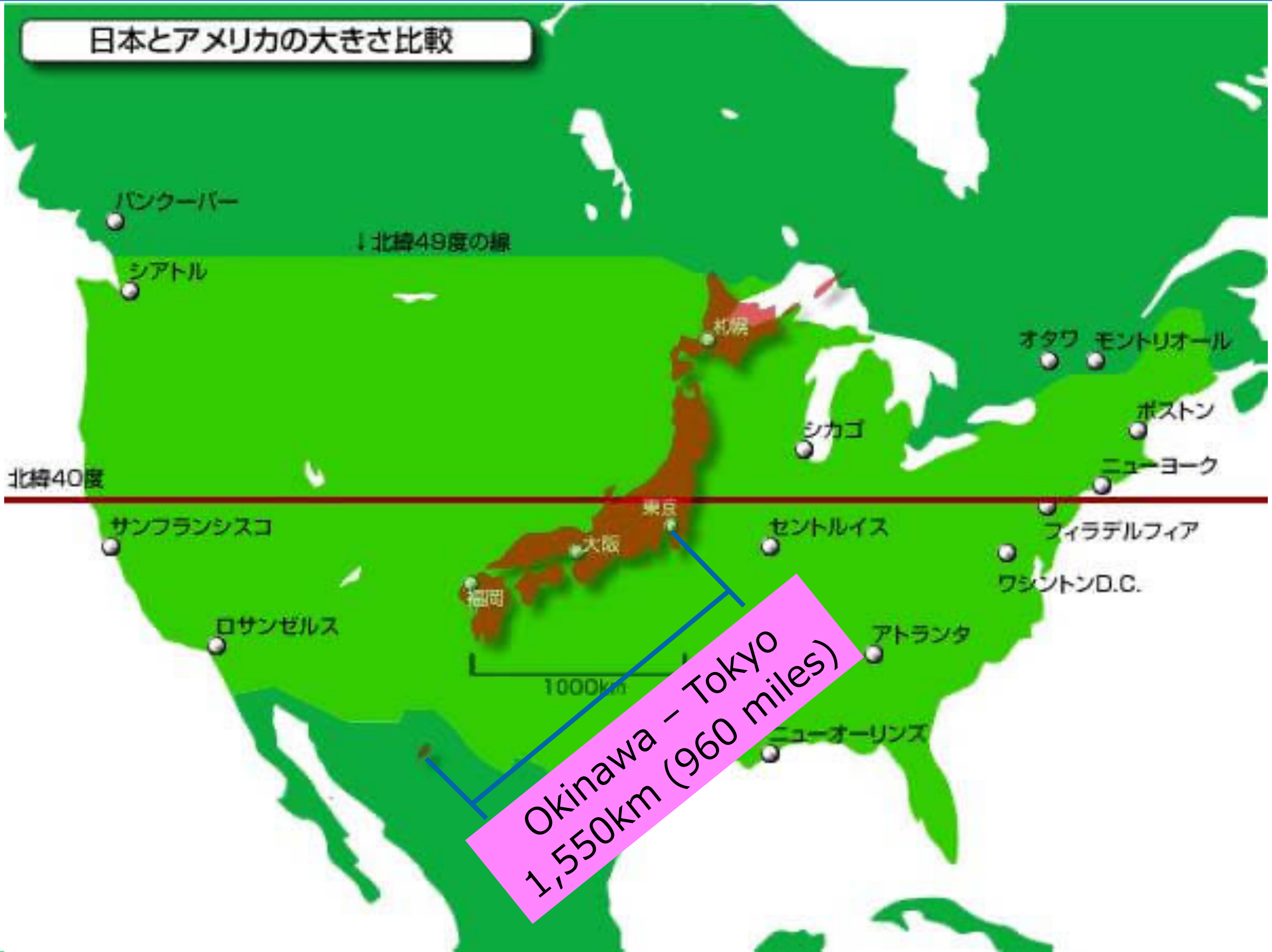
What we can learn from latency on SINET5

		Iwate	Kochi	Mie	Oita	Osaka	Tokyo	Toyama	Yamaguchi	Okinawa
Kitami	←one way latency(msec)	6.65	15.50	13.00	16.70	12.40	9.70	9.97	15.50	22.20
	→one way latency(msec)	6.56	15.50	13.00	16.60	12.50	9.77	9.93	15.50	22.10
	distance (km)	508.00	1443.00	1189.00	1578.00	1238.00	970.00	967.00	1505.00	2436.00
	est. fiber length/distance	2.60	2.15	2.19	2.11	2.01	2.01	2.06	2.06	1.82
Iwate	←one way latency(msec)		9.47	6.94	11.30	7.03	3.63	5.07	10.60	17.30
	→one way latency(msec)		9.46	6.94	11.30	7.12	3.74	5.07	10.60	17.30
	distance (km)		963.40	688.60	1115.00	748.10	463.80	480.20	1056.60	1951.00
	est. fiber length/distance		1.96	2.02	2.03	1.89	1.59	2.11	2.01	1.77
Kochi	←one way latency(msec)			3.31	2.04	2.10	5.51	4.67	2.67	9.25
	→one way latency(msec)			3.32	2.00	2.18	5.61	4.65	2.68	9.23
	distance (km)			303.70	182.00	222.00	612.20	483.20	202.80	990.80
	est. fiber length/distance			2.18	2.22	1.93	1.82	1.93	2.64	1.87
Mie	←one way latency(msec)				5.18	1.45	3.39	2.56	5.03	11.40
	→one way latency(msec)				5.14	1.52	3.48	2.55	5.02	11.40
	distance (km)				481.70	90.70	308.70	227.10	466.70	1267.70
	est. fiber length/distance				2.14	3.27	2.23	2.25	2.15	1.80
Oita	←one way latency(msec)					3.94	7.35	6.51	1.50	7.43
	→one way latency(msec)					4.05	7.48	6.52	1.55	7.43
	distance (km)					395.20	790.20	639.00	105.90	866.50
	est. fiber length/distance					2.02	1.88	2.04	2.88	1.71
Osaka	←one way latency(msec)						3.59	2.74	3.75	7.40
	→one way latency(msec)						3.60	2.64	3.67	10.00
	distance (km)						395.90	270.40	376.20	1202.90
	est. fiber length/distance						1.82	1.99	1.97	1.45
Tokyo	←one way latency(msec)							3.45	7.44	10.10
	→one way latency(msec)							3.31	7.34	13.70
	distance (km)							249.40	769.00	1553.60
	est. fiber length/distance							2.71	1.92	1.53
Toyama	←one way latency(msec)								5.74	13.80
	→one way latency(msec)								5.75	12.40
	distance (km)								590.70	1471.80
	est. fiber length/distance								1.95	1.78
Yamaguchi	←one way latency(msec)									6.85
	→one way latency(msec)									6.83
	distance (km)									956.10
	est. fiber length/distance									1.43

- The fiber length can be estimated to be roughly twice as long as the distance between the cities
  - The delay of fiber is about 5μs/km (5ms/1000km)
- **The latency of the wired network can be constrained** if a SINET-like topology is used.
  - Tokyo-Kitami 970km: RTT 19.47ms
  - Tokyo-Oita 790km: RTT 14.83ms
  - Tokyo-Okinawa 1,550km: RTT 23.80ms

The latency between SINET DCs
Source: NII

Japan is not so small



Resources to support CPS

Resource type		Guaranteed latency and throughput	Deployment and maintenance cost
Network	Wide area network	✓ Can support if properly configured	-
	5G / P5G	✓ Will support	-
Compute	Cloud / Data centers	?	✓ Relatively low
	Network edge	✓ Can support by using dedicated resources for each application	✗ High

Challenges in computing

- Conventional technologies prioritize processing efficiency, often focus on throughput and give little consideration to latency,
  - Memory hierarchy, batch processing, etc.
- Cloud emphasizes cost and throughput
- Most PoC of 5G low latency use cases uses dedicated compute infrastructure
  - Major obstacles to practical deployment of services
- From the perspective of network-connected computing, research and development from the perspective of latency and reliable processing is lacking
  - Technology to appropriately combine and utilize geographically dispersed computing resources is needed, especially in terms of latency and security.

CloudEdge Fusion (CEF) Project

- We will develop technologies to support the realization of a cyberinfrastructure across the cloud-edge continuum to provide optimal processing power (latency, bandwidth, security) in response to service requirements.
- The developed technologies will be integrated as a system towards commercialization and the effectiveness will be verified through practical demonstrations.
- NEDO will fund 77M USD over 5 years (until Mar. 2028)

CEF Project Organization

- NEDO
  - AIST (DigiARC, AIRC)
    - Keio University: Kono Labs, Kondo Labs, Nishi Labs, Kawashima Labs
    - 大阪大学 OSAKA UNIVERSITY: Date Labs
    - Toyohashi Tech: Sato Labs
    - Tokyo Tech: Sakamoto Labs, Endo Labs
    - 東京大学 THE UNIVERSITY OF TOKYO: Nakamura Labs, Sekiya Labs
    - 筑波大学 University of Tsukuba: Tatebe Labs, Amagasa Labs
  - SoftBank
    - 東京大学 THE UNIVERSITY OF TOKYO: Center for Spatial Information Science
    - SSIL: Space Service Innovation Laboratory

Challenges in cloud-edge continuum platform

- **Time-sensitive service execution environment provisioning**
  - Short end-to-end connections enabled in part by geo-positioning resources, so that worst-case latencies in the data pipeline do not exceed service request response requirements.
- **Declarative application deployment**
  - Even if the service provider does not know the details of the infrastructure, applications will be deployed in the right places according to the characteristics.
  - A mechanism is needed to predict and adjust the situation in a timely manner to prevent service interruptions or other SLA violations.
- **Secure service federation**
  - An application can communicate securely with internal/external services, depending on the context and the data it uses.

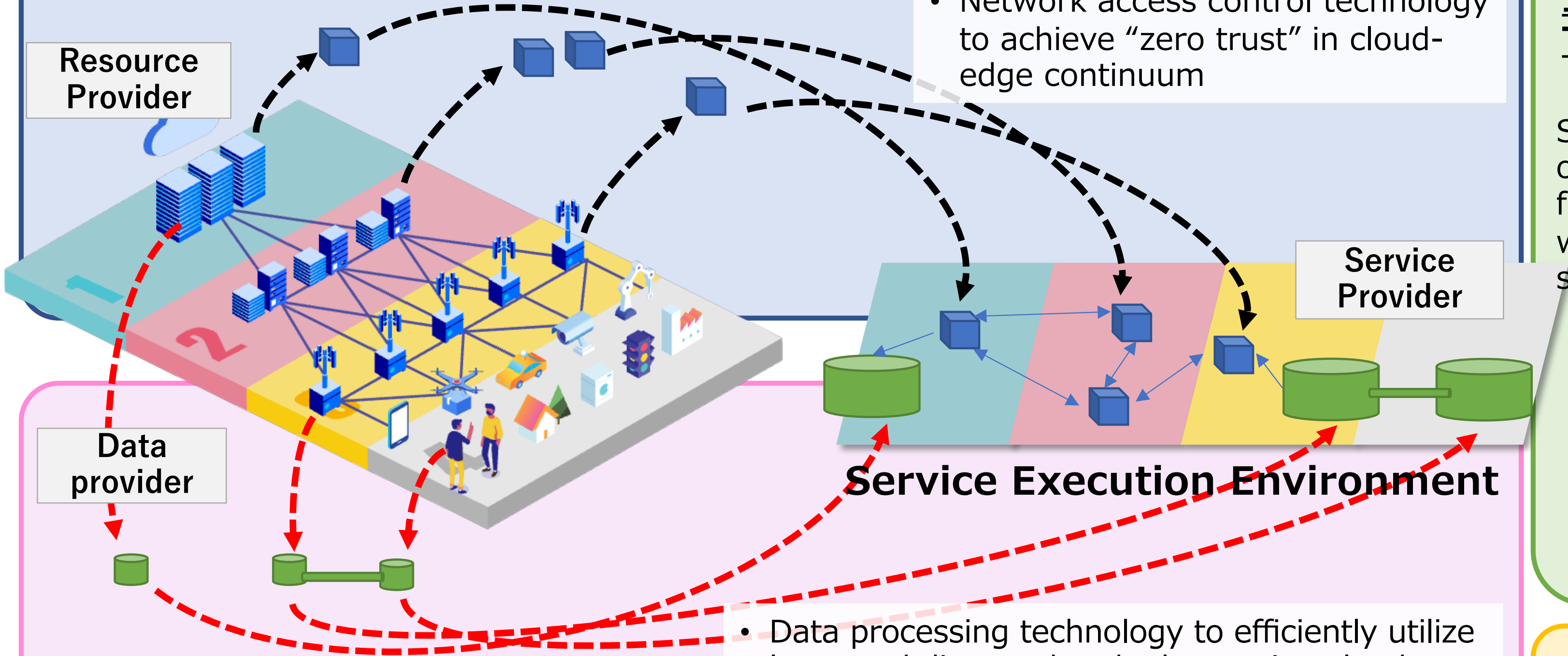
Project items of CEF

- **Project Item (1) Computing continuum service execution infrastructure technology**
  - **Reduce request processing time fluctuation in one order of magnitude or more compared to existing technology (about 100 ms).**
- **Project item (2) Fundamental technologies for continuum data**
  - **Establish elemental technologies for data processing, search, pseudoization, storage management, etc.**
- **Project item (3) System Integration**
  - **integrate the technologies researched and developed in project items (1) and (2) with existing technologies as a system.**
  - **Confirm that the functionality of the computing continuum infrastructure technology satisfies the design and that the performance is sufficient to realize services that require an end-to-end response time of about 100 ms.**
- **Project Item (4): System Demonstration**
- **Project item (5) Promotion of commercialization**

CEF Project Working Packages

(1) Service Execution Technology

- Resource management technology to improve time determinacy
- Network access control technology to achieve “zero trust” in cloud-edge continuum



- Data processing technology to efficiently utilize large and diverse data by leveraging cloud-edge continuum resources
- Pseudo-data technology to facilitate privacy preserving data utilization

(2) Data Utilization Technology

(3) System Integration Technology

System integration of the R&D results from (1) and (2) with existing software

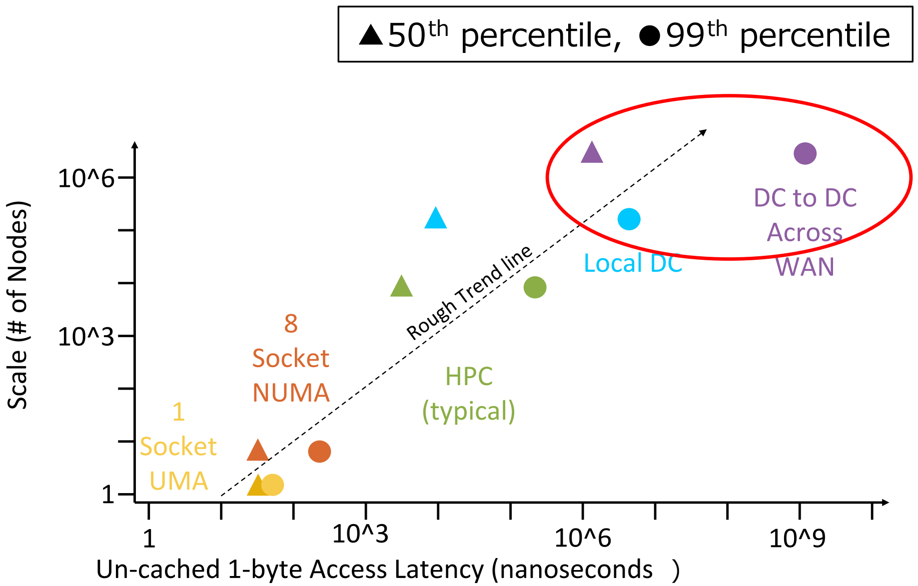
(4) System Demonstration

Demonstration of the proposed platform through industrial application services

(5) Social Implementation and Standardization

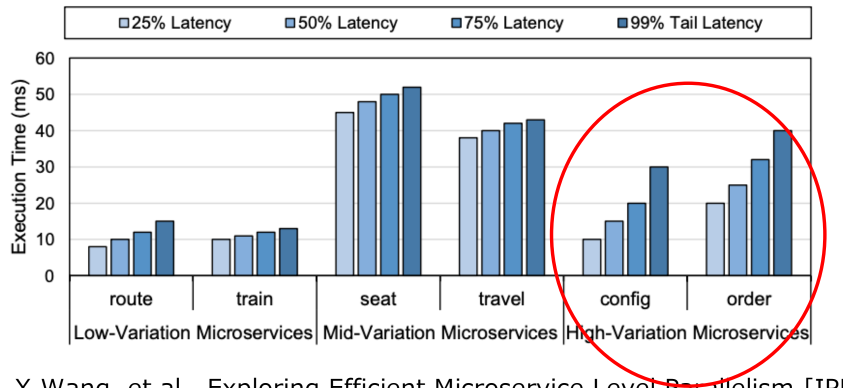
Performance fluctuations in distributed computing

- Real-world data processing requires that the response time to be within the requirements.
- In general, the larger the system, the larger the performance fluctuation.



（出典）Rob Sherwood (Intel) [Exacomm2022]

- The execution time of microservices fluctuates by several tens of milliseconds.



（出典）X.Wang, et al., Exploring Efficient Microservice Level Parallelism [IPDPS2022]

- Real service consists of several dozen microservices.

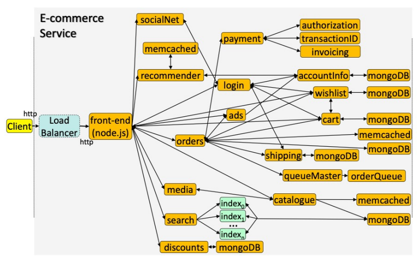


Figure 6. The architecture of the *E-commerce* service.

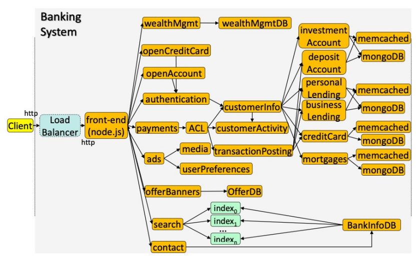
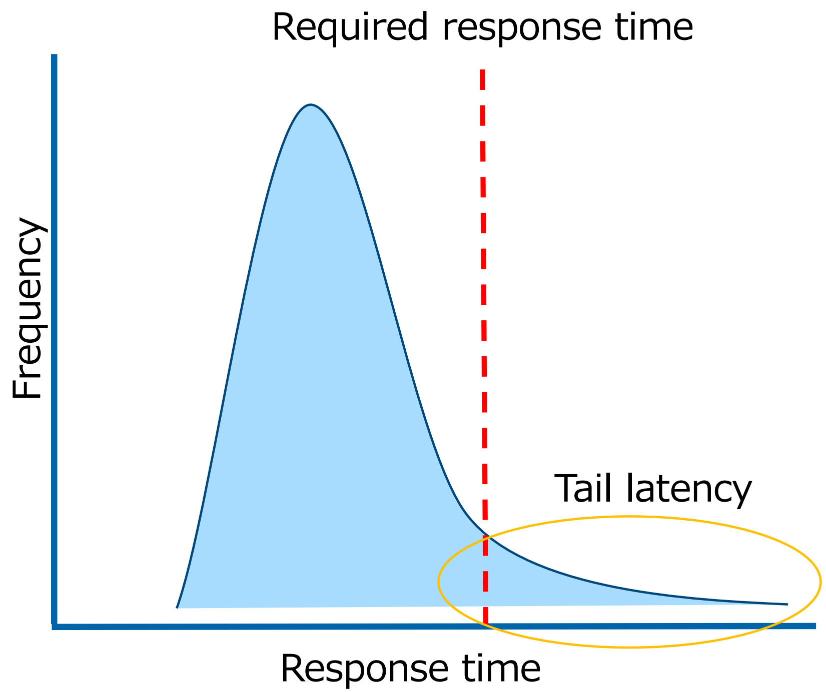


Figure 7. The architecture of the *Banking* end-to-end service.

（出典）U.Gan, et al., An Open-Source Benchmark Suite for Microservices… [ASPLOS2019]

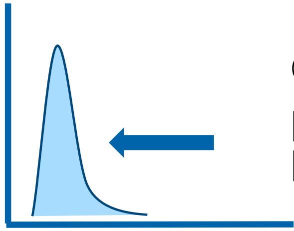
Probabilistic Service Reliability

- Ideally, processing latency and throughput should be fixed, but in reality, this is difficult to achieve in a shared computing infrastructure.
- The response time in distributed system is known to follow “**tail latency**,” caused by various factors:
  - Contention for cache, memory and storage access,
  - Process scheduling
  - Network congestion
- We introduce the concept of "**probabilistic service reliability**" to satisfy trade-offs between performance and economic cost.
  - A platform probabilistically guarantees service levels based on the assumption that there is a certain amount of fluctuation in processing capacity.



Matching and resource allocation

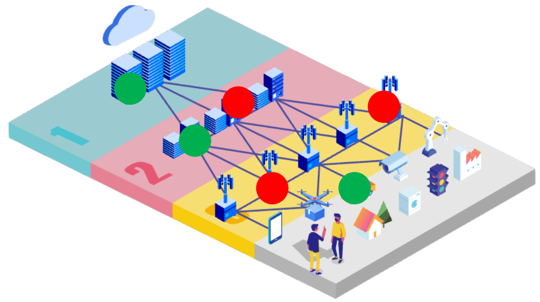
③ Combine resources to provide a service execution environment that meets application requirements.

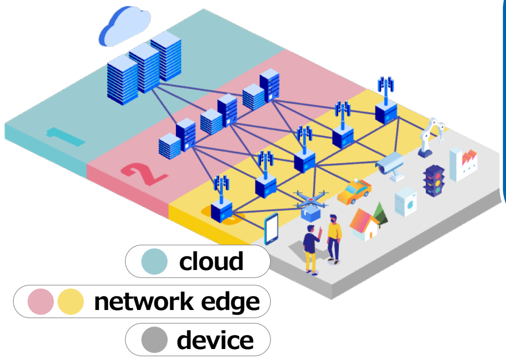


②Reduce fluctuations in performance provided by resources.

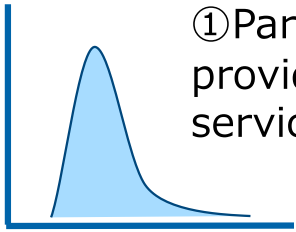
Application requirements (Manifestos)

Matching: Selection of resources



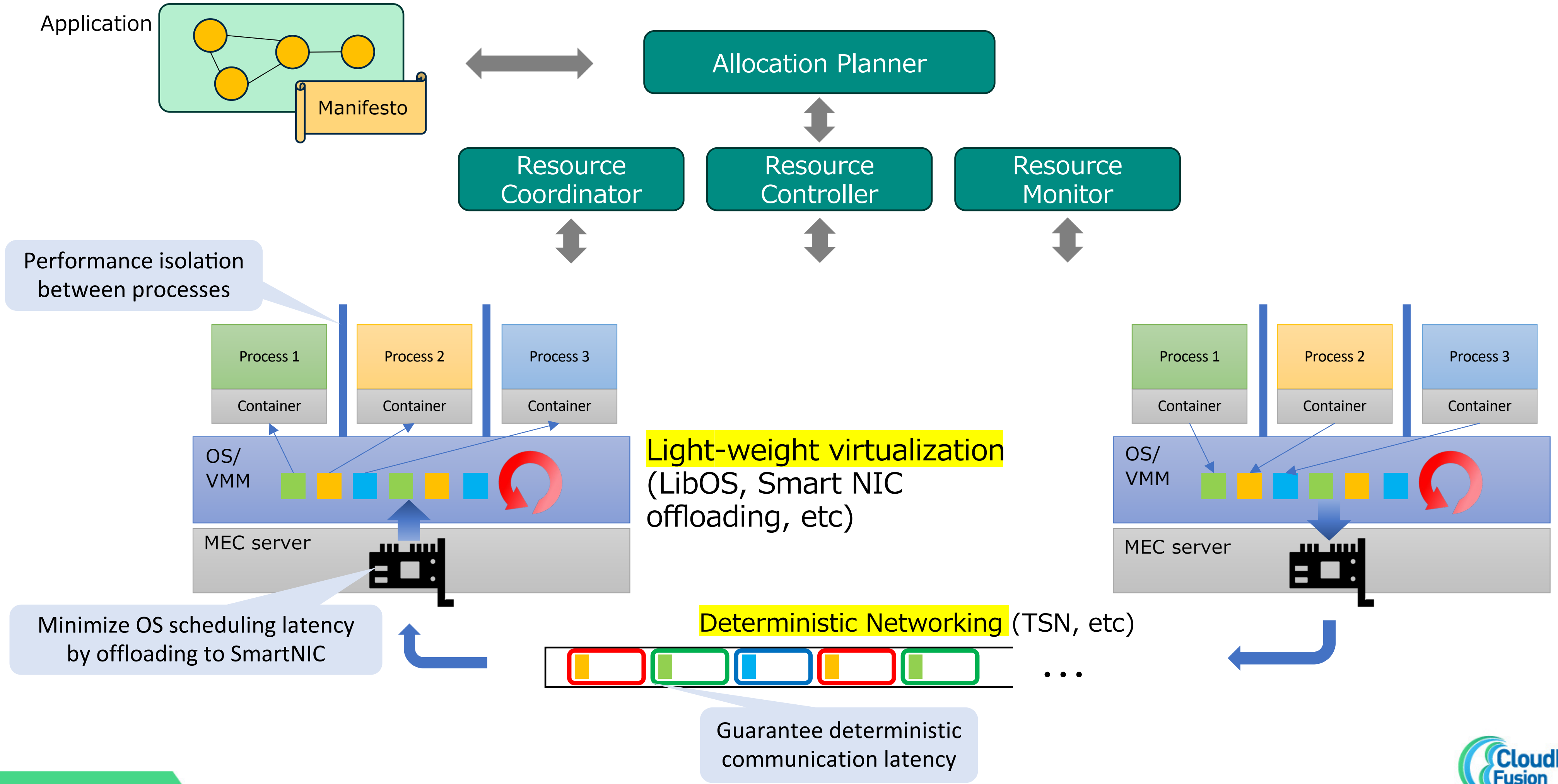


Performance of various infrastructure



①Parameterize the fluctuations in performance provided by resources and define the quality of service that can be provided.

Highly time-sensitive service execution mechanism



Summary

- In a smart society where cyber space and physical space converge, a cyberinfrastructure that satisfies the requirements for processing capacity (throughput) and processing latency (latency) for each service is essential.
- Post-5G communications are designed with these requirements, but today's computing infrastructures such as cloud computing are not designed to address them.
- The CEF project aims to satisfy these requirements and support the realization of a smart society by developing a cyber-infrastructure access cloud-edge continuum to provide optimal processing power in response to service requirements.

Thank you for your attention!

Post-5G Project
ポスト５G情報通信システム
基盤強化研究開発事業

This presentation is based on results obtained from the project ”Research and Development Project of the Enhanced Infrastructures for Post-5G Information and Communication System” (JPNP20017), commissioned by the New Energy and Industrial Technology Development Organization (NEDO).