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Urban OS Supporting the Spread and Development of Smart City

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Abstract

This paper explains the urban operating system (OS), which is a common infrastructure used for efficient data integration and utilization in smart cities. Recently, the utilization of reference architectures has been expanding as a common guideline for smart city design and construction. Within this context, urban OS has become a core element for realizing various urban services that make use of data both within and outside the city. This paper describes the technical requirements for urban OS in the reference architecture constructed by the authors in FY 2019, as well as related initiatives for the development of future urban services such as supercities. Furthermore, it introduces specific examples and technical features of urban OS provided by NEC, along with several cases of using urban OS.

Keywords

Smart city
Urban OS
Data collaboration
Society 5.0

1. Introduction

In light of the spread of the novel coronavirus, there is a growing demand for the acceleration of digital transformation (DX) in various fields, and this applies to urban services provided by municipalities and areas as well. Urban DX initiatives have been pursued worldwide as smart cities since around 2010, and it is predicted that the market size will exceed $4 trillion by 2030 [1]. Additionally, in May 2020, the National Strategic Special Zones Act (Supercity Bill) of Japan was partially revised to accelerate regulatory reforms, inter-sector data collaboration, and the proliferation of advanced services that utilize data, all of which are necessary for realizing smart cities [2].

Efficient data integration and utilization for urban services are key to achieving smart cities. Instead of implementing data integration and utilization functions separately for each service, a common foundation, similar to a computer's operating system (OS), is prepared to enable the realization of various services on top of it. This common foundation is referred to as urban OS. While the use of urban OS is on the rise, mainly centered around open data collaboration, there is also a need for further policymaking and technological development, such as handling personal data, to advance future city services, including the realization of supercities.

In this paper, after introducing international efforts related to urban OS, the requirements and functions expected of urban OS are explained through the introduction of domestic urban OS-related projects. Furthermore, as one of the leading examples of urban OS, the NEC's urban OS along with several application examples is introduced, highlighting the implementation technology.

2. Overseas initiatives

The efforts to establish a common infrastructure for data integration and utilization in smart cities have been pioneered in Europe and other countries, and these common infrastructures can be considered as a type of urban OS. The following is a list of representative initiatives.

2.1. FIWARE

FIWARE is a foundation software developed and implemented under the European Union (EU)'s Future Internet Public-Private Partnership Program (FI-PPP) to facilitate the integration of diverse data [3]. FIWARE is a collection of software modules known as Generic Enabler (GE), and the implementation of each GE is made available as open-source software. The interconnection application programming interfaces (APIs) between GEs and the data models handled by GEs are standardized under the Next Generation Service Interfaces (NGSI) standard, making it an architecture with high extensibility and interoperability [3]. Due to these characteristics, it is used in systems that realize smart cities in numerous cities and companies, primarily in Europe. Moreover, in December 2020, the FIWARE Foundation announced the incorporation of FIWARE's features, including the standard data integration specification NGSI with linked data (NGSI-LD) developed by the FIWARE Foundation, into the India Urban Data Exchange (IUDX), an architecture promoted by the Indian government [4].

2.2. SynchroniCity

SynchroniCity is a pilot project led by Open & Agile Smart Cities (OASC), an international organization for smart cities mainly in Europe, to achieve data interoperability among approximately 20 cities [5]. The SynchroniCity technical framework establishes Minimal Interoperability Mechanisms (MIMs), which are the minimum requirements for interoperability. It outlines common elements to standardize, such as APIs and data models. By adhering to MIMs, different implementations of urban OSs can achieve interoperability, even between different cities. This approach is also reflected in the requirements for urban OSs in the smart city reference architecture in Japan, which will be described later.

2.3. X-Road

The Estonian government provides electronic government services known as "e-Estonia" to its citizens, and its core is the data operability platform known as X-Road [6], which has been operated by the Estonian Information System Authority (Riigi Infosüsteemi Amet, RIA) since 2001. Many organizations, companies, and public institutions in Estonia are connected to the X-Road, and citizens can use their distributed electronic ID cards for paperless access to administrative services such as taxation, police services, education, elections, company registration, and parking fee payments. X-Road, initiated as a pilot project in 1998 and provided as open-source software, has been adopted not only in Estonia but also in Finland, Namibia, and other countries.

3. Domestic initiatives: smart city reference architecture and urban OS

In Japan, the initiative for smart cities began to flourish primarily in the fields of energy and disaster prevention, following the Great East Japan Earthquake. Subsequently, the scope of smart cities expanded to include multiple sectors such as transportation, tourism, the environment, and healthcare. However, many of these initiatives were individually implemented for each sector or city, leading to issues related to efficiency and scalability, which resulted in many remaining at the demonstration stage. To address this, following the examples of advanced initiatives in Europe and other countries mentioned in Section 2, a reference architecture (RA) was developed domestically to serve as a common guideline for the design of smart city systems in Japan, which was done to ensure scalable and interoperability. This RA, along with the urban OS defined within it, is described in the next subsections.

3.1. Smart city reference architecture

In the fiscal year (FY) 2019, the authors constructed a smart city RA for Japan as part of the Cabinet's Office Strategic Innovation Promotion (SIP) Program Phase 2, aimed at advancing smart city architecture design and related demonstration research. This project was commissioned to NEC, Accenture, Kajima Corporation, Hitachi Ltd., National Institute of Advanced Industrial Science and Technology, and the Data Distribution Promotion Council and was jointly conducted by these six companies.

Figure 1 shows the overall image of the smart city RA constructed. To clarify the principle of user-centricity, the service layer is positioned at the center of smart city RA, with the users placed at the highest level. The focus is on how to realize urban services for users. To achieve these services, a dual approach is employed, addressing both the urban management functions (organizational layer, business layer) that are defined by the smart city strategy and are responsible for designing and operating services, and the urban OS (functional layer, data layer, data integration layer), which serves as the foundation for managing and coordinating urban and external data to provide digitalized services. The outcomes of the constructed smart city RA have been published as whitepapers and implementation guidebooks [7], and have been referenced in various government initiatives related to smart city projects.

3.2. Urban OS and its technical requirements

The smart city RA defines urban OS as a complementary element to urban management. Without urban OS, IT systems for realizing urban services would become

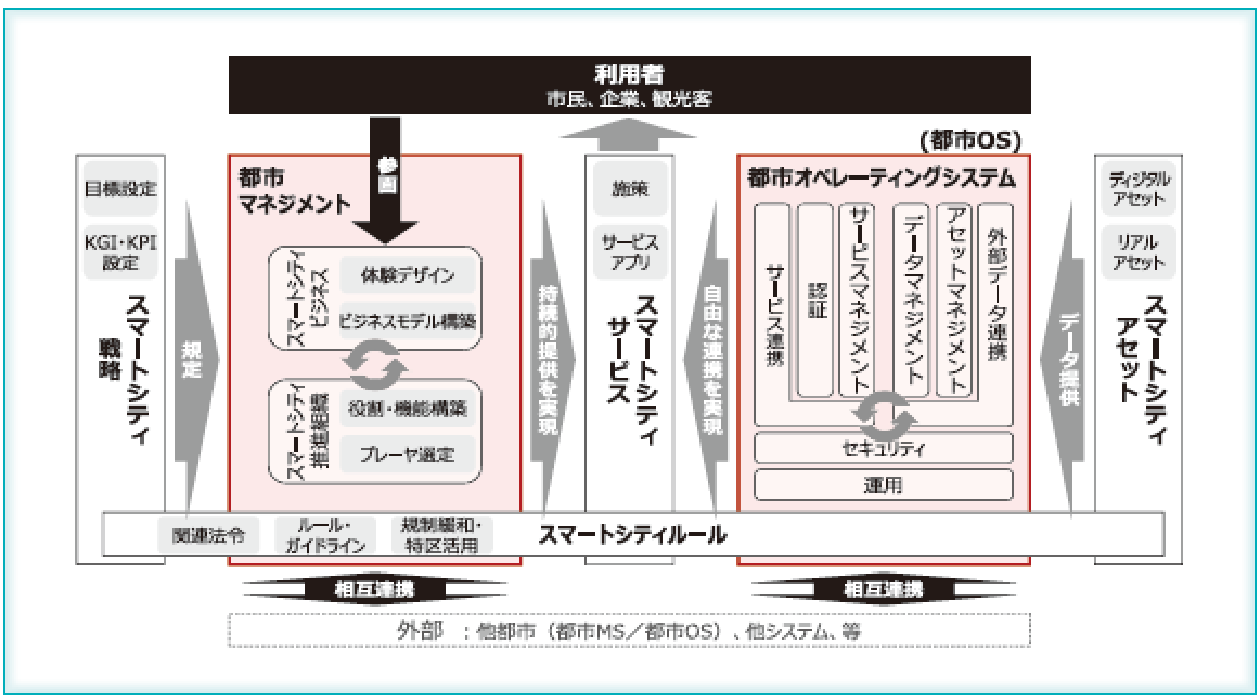

Figure 1. The overall structure of the constructed smart city reference architecture

unique and independent, making data and service coordination and distribution difficult and hindering service scalability. Urban OS is positioned as a common infrastructure for collecting various data from within and outside the city, enabling the realization of applications for urban services through APIs, and connecting with other urban OSs to achieve inter-city collaboration. During the detailed design of urban OS, three requirements were defined based on the current challenges in smart cities:

Interoperability (connectivity): It should provide mechanisms that enable service coordination within and between cities, as well as the reuse of applications.

Data distribution (flow): It should have mechanisms for mediating and coordinating various data from both within and outside the region.

Scalability (continuity): It should provide mechanisms to facilitate expansion in accordance with the functions and architecture updates used in urban OS.

The overall architecture of the urban OS, constructed while considering the aforementioned requirements, is shown in a functional block diagram (**Figure 2**).

To fulfill the first requirement, which is interoperability, mechanisms for API coordination and authentication coordination with services (applications, etc.) and other urban OSs are defined in the functional layer of **Figure 2**. However, rather than limiting specific APIs or data model specifications, the API and data models should be identified in terms of commonality and publicization to facilitate connectivity, along with concrete examples.

Regarding the requirement for data flow, the data layer and data integration layer defined functionalities to incorporate various types of data (metadata, static data, dynamic data, geospatial data, personal data) from other urban OSs, other systems, Internet of Things (IoT) devices, and more. At the core of this functionality is data mediation, serving as a hub responsible for centralized data transfer between data users and the urban OS. Data mediation manages data in two ways: (1) accumulating data within the urban OS and (2) handling data distributed outside the urban OS. Data users can

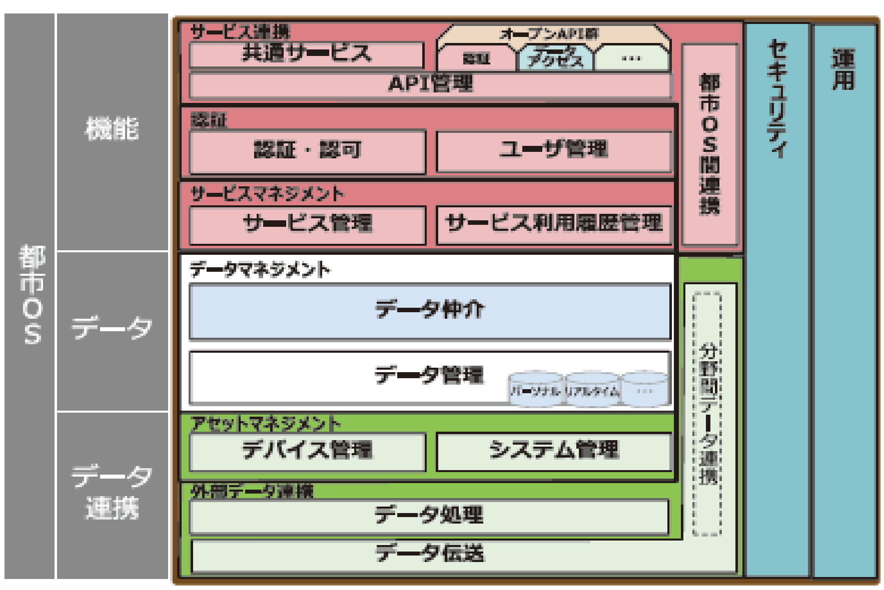

Figure 2. The architecture of the urban OS

access various types of data necessary for realizing urban services without being aware of their locations.

Lastly, for the scalability requirement, it is specified that each functional block shown in **Figure 2** should be detachable, and APIs between blocks should be shared to enable a modular approach to constructing the urban OS, following a building block style. This allows for gradual expansion of the urban OS as smart cities develop, facilitating operations based on minimum functional units and adding functions at the minimum functional unit level.

Furthermore, there are requirements related to security and operations for the entire urban OS, along with guidelines to be referenced. Specifically, for security, the smart city security guidelines described in Section 4.3 provide detailed requirements based on this smart city RA.

4. Related initiatives toward the realization of urban OS

Although the minimum requirements for interoperability have been defined for the urban OS in the smart city RA, several initiatives and discussions have been conducted regarding the specific technical implementation of urban OS and the technological considerations necessary for future supercities realization, which are described below.

4.1. The data collaboration infrastructure for supercities

Currently, the Japanese government is promoting the "Super City Concept," aiming to realize "Whole Future Cities" around 2030, incorporating various cutting-edge technologies [2]. Supercity is positioned as a 'special edition' of a smart city, selected as a National Strategic Special Zone. It aims to achieve advanced services, including regulatory reforms, driven by the local community with the consent of residents. In addition, supercities emphasize cooperation across multiple sectors and services. They are distinct in that they focus on implementation in daily life and society than than just proof-of-concept experiments. The primary concept revolves around improving the quality of life from the perspective of residents rather than being solely provider- or engineer-centric. To achieve supercities, the establishment of a "data collaboration infrastructure" for coordinating multiple sectors and services is considered a core component of the project. It is anticipated that each municipality promoting supercities will adopt this data collaboration infrastructure commonly. The data collaboration infrastructure corresponds to the open APIs in the urban OS shown in **Figure 2** and serves as a minimal set for mutual data exchange and sharing among services provided by the public and private sectors.

The Cabinet Office researched the data collaboration infrastructure in FY 2020, and a report outlined requirements for data intermediaries (brokers), standard specifications for API common rules, and recommended data models to ensure interoperability [8]. These efforts have contributed to the concretization of the infrastructure. Additionally, considering the concept of implementation in daily life and society, much of the data circulating in supercities is expected to originate from individual residents. Therefore, this report also discusses the handling of personal data in the data collaboration infrastructure. Privacy and data protection technologies such as individual consent management, anonymization, and pseudonymization are deemed crucial. Furthermore, to mitigate privacy risks, research has been conducted from the perspective of data decentralization, where personal data is not stored within the data collaboration infrastructure but accessed on a per-need basis, thereby enhancing privacy and security.

4.2. Inter-sector data collaboration infrastructure

In the second phase of the SIP, research is being conducted on the "inter-sector data collaboration infrastructure" to realize cross-sector data utilization and service provision [9]. In order to interoperate data from various fields, the inter-sector data collaboration infrastructure is being studied as DATA-EX equipped with functions such as cross-sector data cataloging, data search, and data connection to facilitate the mutual integration of data from various sectors [10]. For urban OS, the utilization of the inter-sector data collaboration infrastructure provides the potential for efficient collaboration with data already established in other sectors, such as agriculture and transportation.

4.3. Smart city security guidelines

The Ministry of Internal Affairs and Communications (MIC) has issued the "Smart City Security Guidelines (Version 2.0)" to provide a safe and secure smart city environment [11]. These guidelines are based on the layer structure of the smart city RA mentioned in Section 3.1 and outline the security risks and countermeasures required for each category. Moreover, specific security requirements unique to smart cities, such as (1) appropriate supply chain management, (2) collaboration during incident response, and (3) security during data collaboration, are listed, along with examples of collaborative efforts that multiple stakeholders should undertake. To ensure that security measures are comprehensive and that no security considerations are omitted by urban OS providers and service providers, these details are organized into a "Smart City Security Implementation Checklist." Compliance with this guideline is one of the evaluation criteria for the smart city project of the MIC.

5. Urban OS provided by NEC

NEC announced the provision of an urban OS that includes the necessary features for realizing smart cities/supercities in September 2021 [12]. NEC's urban OS is built based on the company's experience and efforts in both domestic and international smart city projects. It conforms to the smart city RA described in Section 3 while incorporating functionalities related to handling personal data and strengthening security, as mentioned in Section 4. Additionally, NEC's urban OS supports various city services, not only domestically but also internationally, including artificial intelligence (AI), biometric authentication, IoT network integration, and other essential functionalities required for realizing diverse urban services. **Figure 3** illustrates the overall configuration of NEC's urban OS, along with its correspondence to the layers of the smart city RA. The following subsections provide explanations of each of NEC's urban OS functions.

5.1. Data collaboration infrastructure

In the core functionality of NEC's urban OS, which serves as the data collaboration infrastructure, the circulation of open data is supported by a data utilization

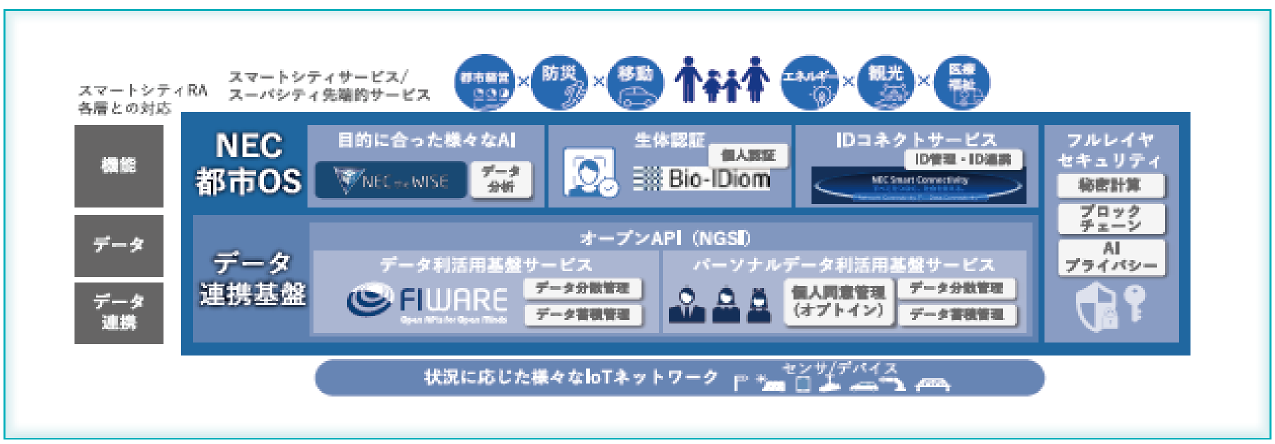

Figure 3. The overall concept of the NEC's urban OS

platform service based on the European-origin global standard FIWARE. For the circulation of personal data, a personal data platform service is provided. This platform adheres to technical standards such as decentralized data management and API publication, which are indispensable for data collaboration infrastructures of supercities mentioned in Section 4.1. It also empowers individuals with control over their personal data, allowing them to share data among service providers based on specific purposes and enabling the provision of data to businesses for product and service development by utilizing data held by various operators.

5.2. Full-layer security

In order to ensure that urban services can be used by citizens with confidence, security is an essential function. NEC's urban OS complies with the requirements set out in the MIC's Smart City Security Guidelines as described in Section 4.3, providing "full-layer security" that includes end-to-end security functions, including protection for networks and IoT devices. **Figure 4** shows a list of security technologies utilized by NEC's urban OS, including authentication/ID management.

As part of its data security features, NEC's urban OS employs techniques such as secure computation to perform calculations and processing while keeping data encrypted [13], and confidential federated learning that enables integrated data analysis by AI across multiple organizations without disclosing individual data [14], thus achieving a balance between the protection and utilization of personal data handled by the urban OS.

In addition, to ensure and record that processes within the urban OS are executed correctly, transaction security features based on blockchain are provided. Furthermore, in the development and operation of the ICT systems, including the urban OS, strict security requirements derived from international standards, government agencies, and industry guidelines are applied. NEC adheres to the NEC Secure Development and Operation Practice Standards to maintain a high level of security throughout the entire system [15].

5.3. Common functions for data utilization and user authentication

In the smart city/supercity, it is expected that urban services that create new value through the use of data across sectors and services will be provided in the future. The NEC's urban OS supports a common set of functions (AI, personal authentication, ID linkage/integration, etc.) that contribute to the value creation of these services. NEC's urban OS incorporates AI engines from NEC the WISE to perform data analysis specifically tailored for smart city and supercity applications [16], provides biometric authentication capabilities, including facial recognition using NEC's Bio-Idiom technology to ensure secure user identification [17], utilizes NEC Smart

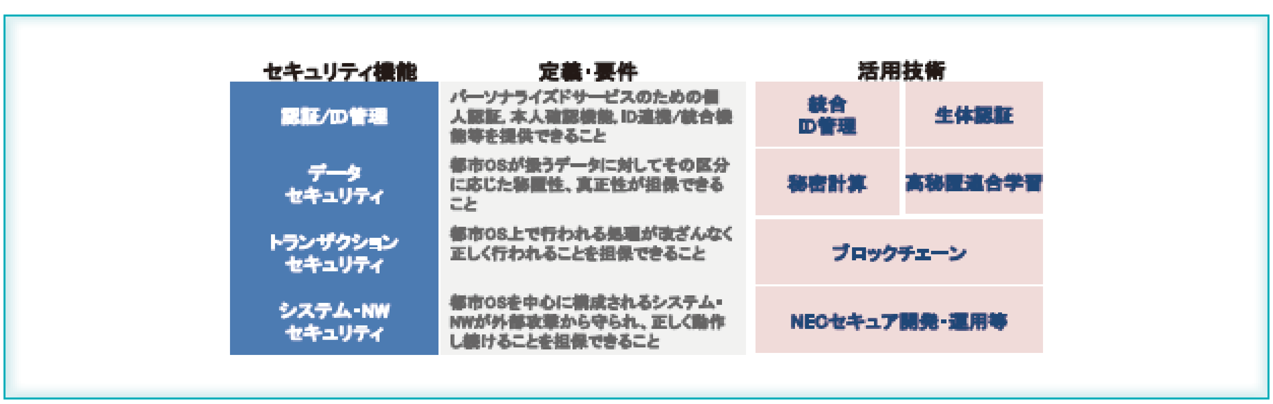

Figure 4. NEC's urban OS security features

Connectivity's ID Connect service to seamlessly link and integrate multiple services for users, enabling them to access various services using a unified ID [18].

5.4. Support for various IoT networks

In the case of smart cities and supercities, it is expected that data acquired from various IoT sensors and devices will be utilized to provide urban services. Therefore, an essential feature of an urban OS is the capability to acquire data from IoT sensors and devices through various network infrastructures. NEC's urban OS supports a variety of IoT networks with different characteristics, such as disaster-resistant self-owned wireless communication networks and high-capacity data-transmitting local 5G networks. These networks cater to different attributes like disaster resilience, availability, communication speed, latency, data capacity, cost, etc., and enable the realization of the required service levels.

6. Examples of the use of urban OSs

The following subsections are examples of smart cities using urban OS in municipalities and regions in Japan.

6.1. Takamatsu city

Takamatsu City in Kagawa Prefecture was selected for the MIC's "Data Utilization Smart City Promotion Project" in 2017, becoming the first example in Japan to

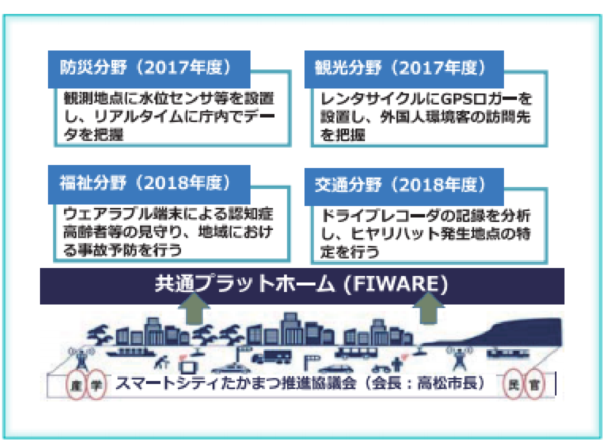

Figure 5. Promotion of the "Smart City Takamatsu" project

establish an IoT common platform, an urban OS using FIWARE. **Figure 5** outlines the project. Takamatsu City prioritized disaster prevention and tourism as key local issues and utilized the urban OS to create a system for collecting, storing, visualizing, and analyzing open data. Going forward, they plan to expand into sectors such as welfare and traffic safety, advancing the "Smart City Takamatsu" project [19].

6.2. Toyama city

Toyama City has constructed the "Toyama City Sensor Network" to realize a smart city by utilizing ICT to improve the efficiency and sophistication of urban functions and services [20]. As depicted in **Figure 6**, the "Toyama City Sensor Network" consists of a citywide wireless communication network (LoRaWAN) and an IoT platform for managing collected data from IoT sensors. The IoT platform uses FIWARE, making it an urban OS. GPS sensors are distributed to elementary school students, enabling the "Community Collaboration Project for Child Safety," which visualizes their routes to and from schools. This project is utilized by elementary schools, the Parent-Teacher Association (PTA), and other organizations to enhance the safety and security of the community. Furthermore, it is made available as a field for verification experiments to domestic private companies, universities, and research institutions, to promote industrial creation. In addition, to address local issues and strengthen disaster prevention capabilities, IoT and other technologies are applied to municipal tasks, contributing to the operation of agriculture status monitoring systems, snow removal status monitoring systems, river water level monitoring systems, and more within the city administration.

6.3. Nanki-Shirahama area

NEC is conducting a demonstration of IoT hospitality services in the Nanki-Shirahama area of Wakayama Prefecture to enhance the satisfaction of tourists and business travelers [21]. In this demonstration, one of the common functionalities of NEC's urban OS mentioned in Section 5.3, facial recognition technology, is utilized. **Figure 7** illustrates the overall concept of this verification. Facial information and credit card information are registered at the airport, which serves as the region's gateway. Subsequently, facial information is detected from cameras installed in hotels, commercial facilities, offices, and other locations, enabling the automatic identification of registered individuals. This facilitates various welcome services, as well as automated processes for hotel room access, shopping, and dining payments in commercial facilities, among other conveniences, to enhance the satisfaction of tourists.

7. Conclusion

This paper describes the concept of urban OS, which serves as a common infrastructure for efficiently coordinating and utilizing data in smart cities. Drawing inspiration from advanced international examples of urban OS, particularly in Europe, efforts in Japan, both public and private, are gaining momentum toward the implementation of a "Japanese version of urban OS." NEC's urban OS represents one concrete implementation, built upon NEC's expertise and

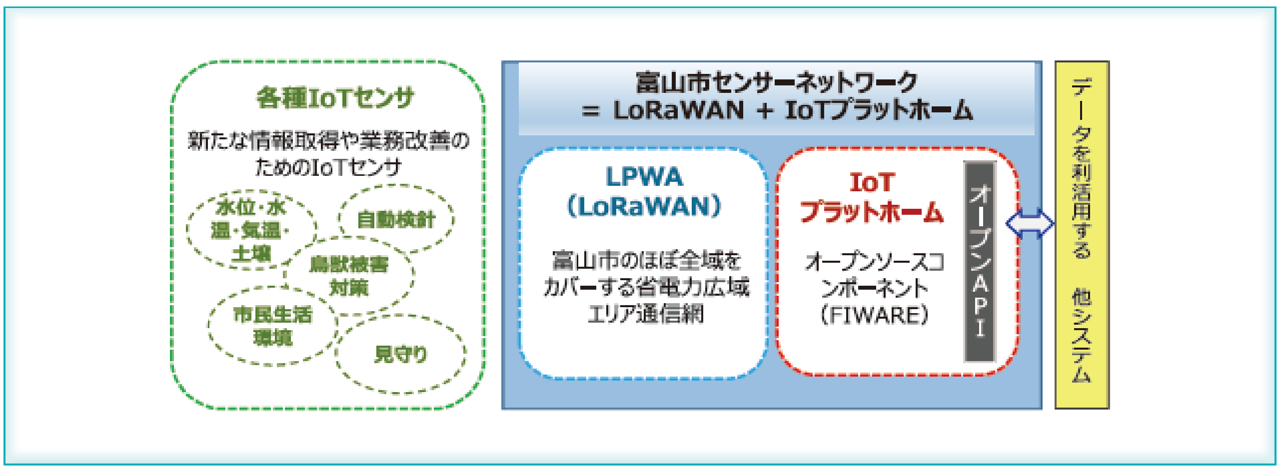

Figure 6. Toyama City Sensor Network

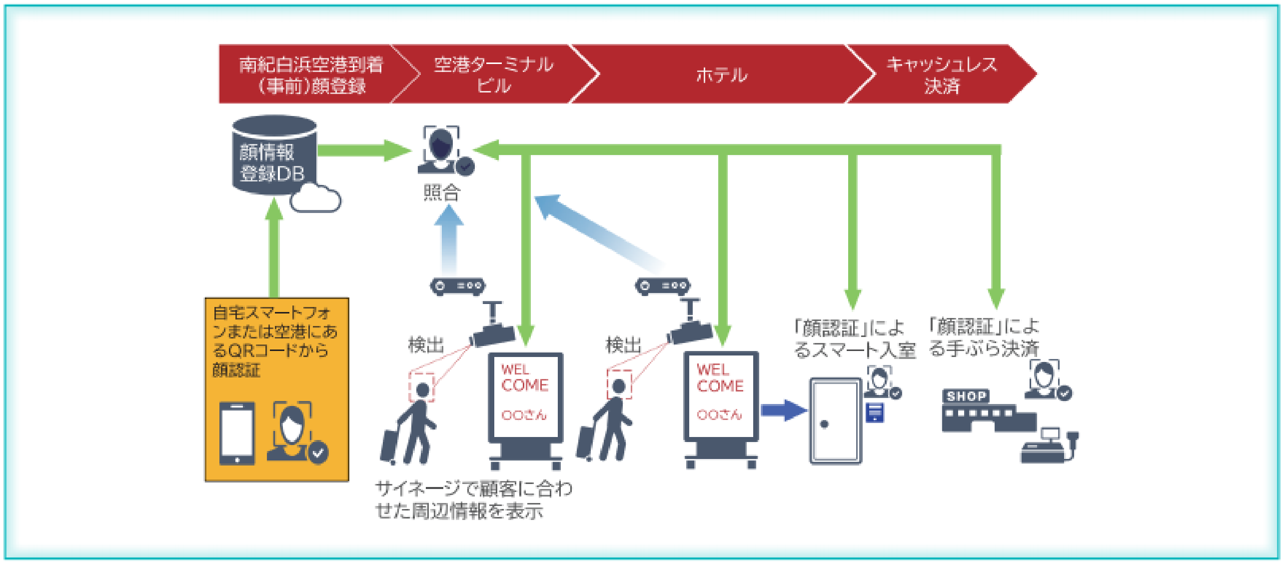

Figure 7. IoT hospitality services in the Nanki-Shirahama area

experiences in domestic and international smart city initiatives. It incorporates various essential features necessary for realizing urban services, including the utilization of personal data and full-layer security, not only within Japan but also internationally.

In the future, it is anticipated that urban OS will become a common adoption across municipalities and regions providing smart city services. This will usher in an era where these cities compete by delivering attractive urban services tailored to each region's unique strengths through data-driven approaches.

Disclosure statement

The authors declare no conflict of interest.

References

[1] REPORT OCEAN. Press Release, https://www.reportocean.com/
[2] Cabinet Office. National Strategic Special Zone Super Cities, https://www.chisou.go.jp/tiiki/ kokusentoc/supercity/openlabo/supercitycontents.html
[3] Nakamura Y, 2021, Data Processing and Utilisation Infrastructure for Advanced DX and Examples. Shinrigaku Journal, 104(9): 981–988.
[4] India Urban Data Exchange, https://iudx.org.in/
[5] SynchroniCity, https://european-iot-pilots.eu/project/synchronicity/
[6] e-Estonia. X-Road, https://e- estonia.com/solutions/interoperability-services/x-road/
[7] Cabinet Office. SIP Cyber / Architecture Construction and Demonstration Research Results Publication, https://www8.cao.go.jp/cstp/stmain/20200318siparchitecture.html
[8] Cabinet Office. Study on Data Collaboration in Super Cities / Smart Cities, https://www.chisou. go.jp/tiiki/kokusentoc/supercity/supercity_ kentoukai.html
[9] Council for Science, Technology and Innovation, Cabinet Office. Establishment of Data Federation Infrastructure, https://www8.cao.go.jp/cstp/tyousakai/juyoukadai/14kai/siryo2-1.pdf
[10] Data Society Promotion Council. DATA-EX Initiatives, https://data-society-alliance.org/dataex/
[11] Ministry of Internal Affairs and Communications. Smart City Security Guidelines (Version 2.0), https://www.soumu.go.jp/main_content/000757799.pdf
[12] NEC. NEC Urban OS, a Cloud Service that Combines AI and Biometric Authentication Technologies to Provide the Functions Required for Super Cities, https://jpn.nec.com/ press/202109/20210908_02.html
[13] NEC. Secret Computing, https://jpn.nec.com/securecomputation/
[14] NEC. Highly Confidential Coalition Learning: Combining Privacy and Confidential Information Protection with AI Applications, https://jpn.nec.com/rd/special/202103/index.html
[15] NEC. Information Security Report 2021, https://jpn.nec.com/csr/ja/security/index.html
[16] NEC. NEC the WISE, https://jpn.nec.com/ai/index.html
[17] NEC. Biometrics, https://jpn.nec.com/biometrics/index.html
[18] NEC. Smart Connectivity, https://jpn.nec.com/solution/smart_connectivity/index.html
[19] Takamatsu City. Smart City Takamatsu: Overview of Initiatives, https://www.city.takamatsu. kagawa.jp/kurashi/shinotorikumi/machidukuri/ smartcity/index.html

[20] Toyama City. About Toyama City Sensor Network, https://www.city.toyama.toyama.jp/ kikakukanribu/smartcitysuishin/toyamaSN.html
[21] NEC. Launch of ‘IoT Hospitality Service Demonstration’ in the Shirahama Area, Wakayama Prefecture, https://jpn.nec.com/press/201812/20181213_02.html