CPaaS.io: An EUJapan Collaboration on Open Smart City Platforms

Noboru Koshizuka (The University of Tokyo)
Stephan Haller (Bern University of Applied Sciences)
Ken Sakamura (Toyo University)

Abstract

Data-driven cities and governments rely significantly on data collection, management, and distribution platforms. In this article, we introduce CPaaS.io, a collaborative project between Japan and the European Union with the goal of establishing common smart city platforms for deployment in real smart city use cases.

1 INTRODUCTION

Today, data are crucial to the functioning of society. In fact, it is sometimes said that the most competitive area in information and communications technology (ICT) is not algorithms but data. The ICT National Strategy of Japan known as Society 5.0 proposes a data-driven society in which data help solve problems in the fields of mobility, supply chains, healthcare, and lifestyle to name a few. This will generate further economic growth and increase quality of life. Consequently, both in Japan and the European Union (EU), data have been termed the oil of the 21st century. These data come from a variety of sources: the Internet of Things (IoT) and sensors, open government resources, social media, and industry and business repositories, not to mention the wealth of personal information from individual users. These can be obtained, linked, and analyzed to extract valuable intelligence and transform our society for a better future. In the deployment of smart city services, providing a platform for data collection, management, and distribution is crucial.

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2 CPaaS.io: CITY PLATFORM AS A SERVICE—INTEGRATED AND OPEN

To reach these goals, we have started a joint smart city platform project, CPaaS.io: City Platform as a Service— Integrated and Open (`www.cpaas.io`), funded by the European Commission under the Horizon 2020 program as well as the Japanese government. It was started in July 2016 and completed in December 2018. The project is a collab.oration among organizations in Japan and Europe. The project is coordinated by the Yokosuka Telecom Research Park, Inc. Ubiquitous Networking Laboratory (YRP UNL) in Japan and by the Bern University of Applied Sciences in Europe. On the Japanese side, the project partners include Microsoft Japan, Access Co. Ltd., Ubiquitous Computing Technology, Inc., and The University of Tokyo; on the European side, partners include AGT Group (R&D), NEC Laboratories Europe Ltd., Odin Solutions, The Things Industries, and the University of Surrey.

CPaaS.io is a project to develop a data-driven smart city platform for solving urban issues and supporting regional or even global applications that cities in Japan and the EU face today. Smart city is one of the hottest topics in the ICT area.

The are many smart city projects and platforms around the world[1, 2], all different from each other and each exhibiting unique points and novel features. Our smart city approach is data-driven and forms the basis for a smart city data infrastructure. The CPaaS.io platform we are developing assumes the role of such a smart city data infrastructure and, technically speaking, is a full-fledged ICT-based platform with functions for collecting, integrating, distributing, and sharing data. It is also equipped with the necessary access control and security functions for proper data governance.

The integration of IoT data enables city authorities to see in real time what happens in their city, an important capability for better managing the smart city. In addition, publishing open data helps improve transparency and enables third parties to build value-added services on top of the infrastructure, thus fostering a dynamic economic environment, particularly for startups. Technical challenges being addressed include data provenance, data quality, adaptive privacy levels, policies, and adaptive processes for distributing and deploying intelligence to the cloud or edge.

The CPaaS.io platform is designed using a common functional architecture, but individual platform instances are implemented based on two different sets of technologies. In Japan, CPaaS.io is implemented based on the Ubiquitous ID 2.0 (u2) architecture[2, 4] while the European instance is based on FIWARE. The u2 architecture is an architecture for IoT platforms coming out of the TRON Project of Japan (`www.tron.org`); FIWARE is an infrastructure framework for cloud and IoT solutions widely deployed in the EU (`fiware.org`). As shown in Figure 1, a loosely coupled federation between these platforms is possible using linked data and open application programming interfaces (APIs). We will describe these two architectures more precisely later in the article. Before

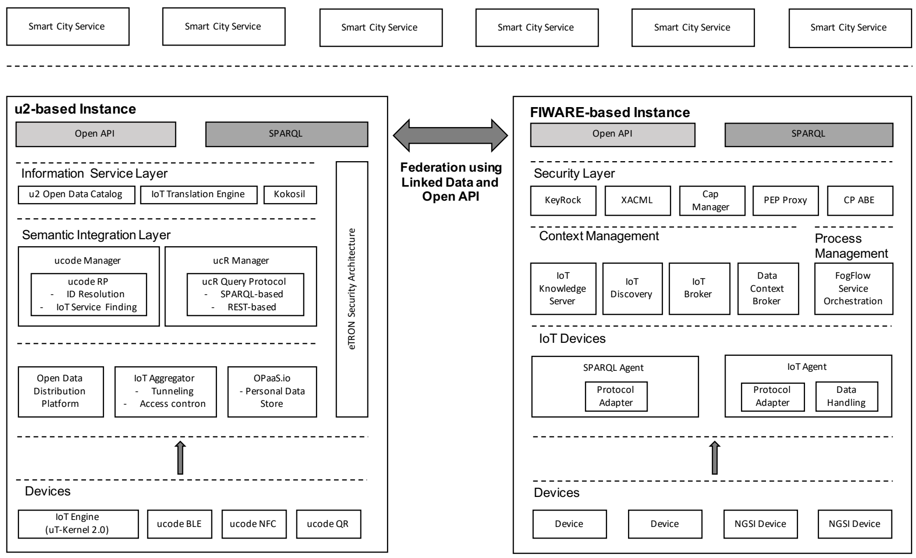


Figure 1: The CPaaS.io platform architecture showing the components and the federation between a u2-based instance and a FIWARE-based instance. CAP: capability; PEP: policy enforcement point; CP ABE: ciphertext-policy attribute-based encryption; NFC: near-field communication.

explaining the individual technical components, we first consider some use cases for the platform.

3 SMART CITY USE CASES

Practical use cases are being implemented in cities in Japan and Europe. The use cases in Japan have been selected with the upcoming 2020 Tokyo Olympics in mind, targeting issues relevant to this major event and allowing the incorporation of lessons learned from the project's experimental implementations to be incorporated into other cities' planning. Thus, the major use cases in Japan are public transportation in Tokyo, tourism support (tested at Sapporo's yearly Snow Festival), and emergency medical service in Yokosuka City. In Europe, on the other hand, the following use cases are being implemented: water control to avoid floods after heavy rain in Amsterdam, management of public events like the Color Run (`thecolor.run.com`), and smart parking in Murcia, Spain.

3.1 Open data of public transportation, Tokyo

Public transportation is one of the most important and complex infrastructures for the basic functioning of large cities. This is especially the case for the public transportation network in Tokyo—one of the most complex in the world with

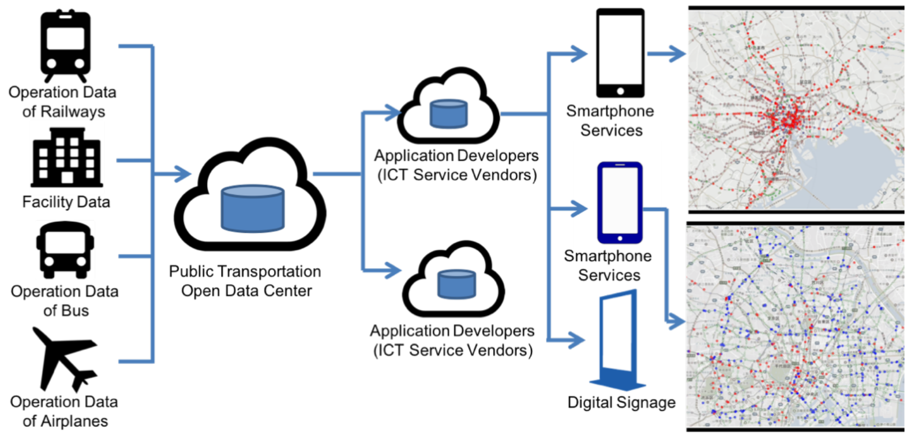


Figure 2: The Public Transportation Open Data Center providing both static and real-time location data of trains and buses in Tokyo (red dots show train positions and blue dots show bus positions).

hundreds of railway stations and thousands of bus stops and routes. Moreover, these are operated by many private companies: approximately 50 railway companies, more than 100 bus companies, and over 1,000 taxi companies.

Today, advanced public transportation operators around the world provide information services, such as transfer guidance based on timetables, and operational information services, such as delays and route troubles. In the case of a megacity with advanced public transportation networks like Tokyo, open data offers the best approach for providing integrated information.

The Association for Open Data of Public Transportation (ODPT) is currently making efforts to build a Public Transportation Open Data Center offering information on railways, buses, airlines, and all other means of transportation in Tokyo (Figure 2). The demand for open data of public transportation has become very high, and the number of association members has increased to 56 corporations (as of 23 April 2018) and nine observers.

From the standpoint of technology, ODPT uses IoT and open data for this activity. Static data, such as timetable and station map data, can easily be distributed using only open data technologies, but dynamic, real-time data, such as train/bus location and their real-time operation status data, must be dealt with using IoT technology such as sensor networks and geolocation systems.

3.2 Location-aware city guide services based on open data, Sapporo

International tourism is a big industry both in Japan and Europe. For example, in 2016, the number of international tourists arriving in Japan increased to over 24 million; in the EU, close to 500 million arrivals were counted. Clearly, tourism support is a relevant application for the smart city. Sapporo is one of Japan's most popular tourist cities, offering nearby ski resorts, hot springs, and many other attractions. Promoting tourism using digital technologies and a smart city platform is very much in the interest of Sapporo.

In a joint project with the city, we first established the Sapporo Open Data Association in 2016 with 22 organizations (`sapporo.odcity.org`). This association conducts research, such as studying open data provisioning and its uses for Sapporo tourism and public transportation, and holds events like application contests, hackathons, and ideathons; promotes open data usage; and encourages application usage on smart phones during feasibility study experiments. We have collected, integrated, and published many data sets related to tourism, e.g., sightseeing, hotel, restaurant, and public transportation information. For the latter, we use the Public Transportation Open Data Center, as mentioned previously.

Next, we developed a mobile application, Kokosil Sapporo (`home.sapporo.kokosil.net/en/`), which provides information based on the open data for Sapporo tourism and using location-aware technologies. With a geospatial position recognition system using GPS and Bluetooth Low-Energy (BLE) beacons, tourists can get information they need in a timely manner.

The approach of combining open data and IoT technology on the CPaaS.io platform has proven to be efficient for tourism information development, in particular regarding the governance of data and systems as well as the sharing of responsibilities among government and industries. In the case of Sapporo, the local government provides open data for tourism and an IoT infrastructure, such as BLE beacons, and the tourism industry provides services and applications for tourists. We have already deployed such tourism information services for big events like the Sapporo Snow Festival in 2016 and 2017 and the Asian Winter Games in 2017 [Figure 3-(a)].

3.3 IoT emergency medical services, Yokosuka

IoT emergency medical services are made possible by teamwork among rescue crews in ambulances and staff at hospitals and dispatching headquarters. Information sharing is very crucial to provide smooth emergency medical care. Yokosuka City and YRP UNL in Japan have jointly been developing the IoT Emergency Medical Support System on the CPaaS.io platform, which collects information from emergency hospitals and ambulances to share among the involved groups.

Our system is very simple technically, as it transmits the video images of patients in ambulances, facilitating information sharing between the rescue crew and the doctors at the hospitals in real time using tablet devices and Internet Protocol cameras placed in ambulances [Figure 3-(b) and (c)]. The system also transmits real-time location information of ambulances to emergency hospitals so that the staff knows when the ambulance will arrive. Thus, they can prepare for receiving patients smoothly and facilitating handover. This system has been adopted for all of the emergency medical care crew units since 2014 in Yokosuka

Figure 3: The Sapporo open data for tourism and Yokosuka smart ambulance using IoT technologies. (a) A location-aware information service showing tourist information from open data using Kokosil Sapporo and BLE beacon. (b) The inside of a smart Yokosuka ambulance. (c) A doctors' screen showing vital signs monitoring (bottom) and the position of the ambulance and a patient image (top). (Photos courtesy of YRP Ubiquitous Networking Laboratory, Japan.)

and since 2017 in neighboring Miura.

3.4 Waterproof Amsterdam

Disaster prevention is an important issue in cities and is also a good application of smart city platforms, such as the CPaaS.io platform. Flooding is a major hazard in The Netherlands because large parts of the country are below sea level, and the problem has increased with global warming.

Hence, The Netherlands has, over the years, invested heavily in infrastructure, dikes, and smart technology to keep its citizens safe and dry. Because Amsterdam also aspires to be "waterproof," several pilot projects are examining solutions for this issue.

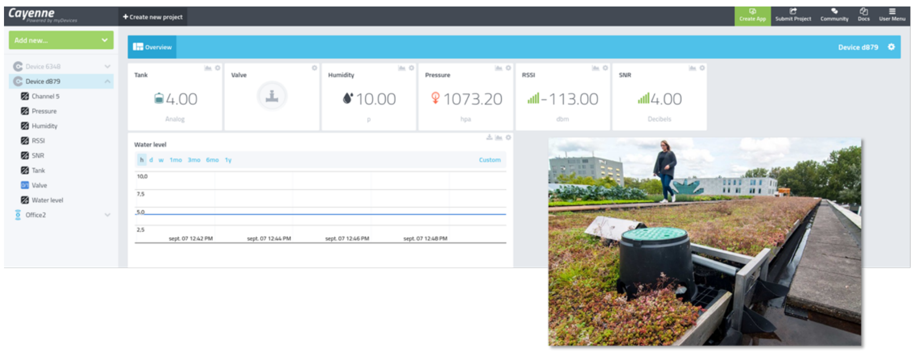
As part of the CPaaS.io project, we are deploying smart water buffers on rooftops, controlled through an IoT LoRaWAN. Data from the water buffers and the sewage system are combined with additional data like weather forecasts in a back-end application for analysis and pattern detection, e.g., when heavy rain is forecast, the valves of the buffers are closed, keeping rain water in the buffers and preventing flooding of the sewage system. Once the sewage system has regained enough capacity, the valves can be opened again [Figure 4-(a)].

3.5 Color Run: Managing public events

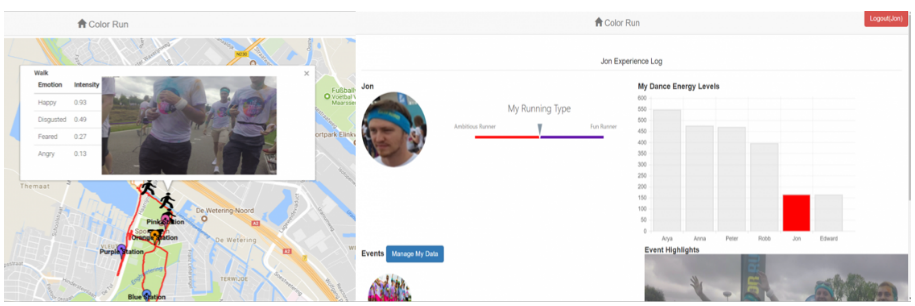
International tourism is a big industry in Europe. The focus here is not just to provide information but to enhance the visitor experience in participatory events, such as the Color Run, a series of events held at different locations around the world. In the CPaaS.io project, we have used one of these events to demonstrate what IoT sensors and analytics can add to such an event. By providing runners with wristbands, deploying video cameras along the course, and linking the data with geospatial information provided by the city, we are able to create personalized experiences. For instance, wristband data can be used to extract trajectory, effort (heartbeat), and excitement levels during the events. Video analytics solutions can be used to create dynamic, geolinked color maps that can be linked to runners' sensor trails [Figure 4-(b)].

4 EU AND JAPAN INSTANCES OF THE CPaaS.io SMART CITY PLATFORM

In the CPaaS.io project, we have defined a layered functional architecture for a smart city platform. Based on this architecture, concrete platform instances have been developed and set up both in Japan and in Europe, building on top of existing platforms and frameworks that are commonly used in the respective regions, as shown in Figure 1. The smart city platform instance in Japan is based on the u2 architecture, while the smart city platform in Europe is based on the FIWARE architecture.



(a)



(b)

Figure 4: Waterproof in Amsterdam and a Color Run event. (a) A pilot system hardware and screen of the dashboard system for the Amsterdam waterproof use case. (Photo courtesy of Dakdokters.) (b) A running tracking system view of the Color Run use case in Utrecht, The Netherlands. (Photo courtesy of AGT.) AI: artificial intelligence; UI: user interface.

While these implementation architectures are quite different regarding existing APIs and data format specifications, both provide common functions from a service-level point of view. For example, both provide a semantic data platform based on semantic web technology, an open data platform, personal data management, IoT device management, virtualization functions of IoT devices, security functions, service finding functions, and so on. Because of these commonalities, the federation of platform instances becomes possible on the semantic level, as we will show after first discussing how the two implementation architectures look.

4.1 u2-based architecture

The left side of Figure 1 shows the u2-based smart city platform architecture. The u2 architecture has been developed as part of the TRON Project, an ongoing effort that originally started in 1984 as probably the world's first project on the IoT. So far, more than 1,000 companies and organizations worldwide have contributed to it and to publishing the TRON standards, industrial open standard specifications for IoT systems.

4.1.1 ucode and ucR

In developing an IoT-based architecture standard, we need to explore the essence of IoT or ubiquitous computing: context awareness.

So the central point of the u2 architecture is a context-aware computing mechanism: either a standard for context representation or a standard for acquiring context information management. In the u2-based architecture, the ucode and ucR standards deal with these issues[4].

ucode: In terms of the context representation, we need a consistent system for determining the identity, location, and status (who, what, where, and when) of real-world entities. In the u2 architecture, every real-world entity is assigned a ucode, a 128-b unique identifier that has been adopted as International Telecommunication Union-Telecommunication Standardization Sector Recommendation H.621.1 (2012).

ucode Relation (ucR): The u2 architecture represents the real-world context by modeling the relationships of real-world entities. The ucR model defines the relation of an entity identified by a ucode with another entity also identified by a ucode or with a literal value, such as a string, number, or date. The relation itself is also repre.sented by a (relation) ucode. These three ucodes are the basic unit of the ucR model and are hence also called a ucR unit. In a sense, the ucR model is similar to triples used in the Semantic Web [e.g., Resource Description Framework (RDF)]; but, while the Semantic Web uses uniform resource identifiers, the ucR model relies on ucodes.

4.1.2 ucode manager and ucR manager

The wide-area distributed database that manages ucR is called a ucR database. The ucR database comprehensively manages information on the relations among multiple ucodes, in addition to the content such as information services associated with individual entities to which ucodes are assigned. The ucR database is basically an open database that anyone can use to reference or register information; if needed, however, access control can also implemented.

When a user physically accesses an entity in the real world, the u2 architecture identifies the appropriate information for the situation from the ucR database, based on the ucode assigned to the entity. This process is called ucode resolution. Moreover, the information associated with ucodes, i.e., the ucR graph, is registered in the ucR database. The protocol for accessing the ucR database in this manner is called ucode Resolution Protocol and is implemented in the ucode Manager. The ucR graphs, on the other hand, can be queried using SPARQL or RESTful APIs via the ucR Manager.

4.1.3 IoT aggregator

We have been investigating the concept of aggregate computing1 and its realization framework, called IoT Aggregator[3, 5]. As shown in Figure 5, aggregate computing lets the devices, services, and systems connected to the network cooperate with each other to achieve an optimal environment.

The IoT Aggregator mainly provides three functions in IoT cloud computing. First, it offers standardized access to IoT edge nodes, abstracting from the different native interfaces of each node. Via the IoT Aggregator, IoT applications can communicate and collaborate with IoT edge nodes much more easily. Second, it provides light-weight IoT security functions based on the eTRON security framework by establishing virtual encrypted tunneling links between virtual objects in cloud servers and real objects in edge node devices. Third, it provides a flexible access control function in the IoT Aggregator cloud services. In IoT applications and services, access control to the devices and their functions is essential and usually requires heavy computation power because flexible access control must manage a large number of governance policies, which can change dynamically according to the real-time smart city context.

Figure 5 shows that access control is implemented on the virtual object in the IoT Aggregator cloud system based on access control policy.

4.1.4 Omotenashi platform (OPaaS.io)

The IoT environment and smart city services need to learn and collect the attributes of each individual user, such as language spoken, age, pertinent physical characteristics, preferences, and so on. Such knowledge must be reflected in the creation of an optimized environment. For this purpose, the u2-based smart city platform includes a general-purpose personal data store. The platform is targeted to manage personal information of visitors to the 2020 Tokyo Olympic Games, so we call this OPaaS.io or *Omotenashi* (hospitality) cloud.

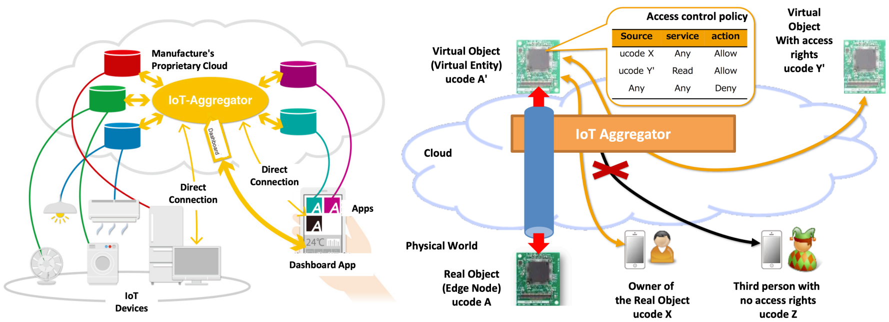


Figure 5: An IoT aggregator.

4.1.5 T-Kernel 2.0

T-Kernel 2.0 (IEEE Std. 2050-2018) is a lightweight real-time operating system with small footprint; it is open source software and adequate for the IoT edge node devices. The standard edge nodes of the u2-based architecture use T-Kernel 2.0.

4.2 FIWARE-based architecture

FIWARE is a smart-solution platform consisting of a number of so-called generic enablers, with which cloud-based service platforms can be built. Open source reference implementations are available for these enablers as well as public and royalty-free APIs that support the development of smart applications in multiple vertical sectors. FIWARE has grown out of a significant effort of the European Commission involving many partners mainly from industry but also academia. It is used in many European projects as well as many smart city deployments (e.g., Vienna), and its use is encouraged by the Open and Agile Smart Cities initiative (`oascities.org`).

The components of the FIWARE-based CPaaS.io instantiation are shown on the right side of Figure 1. We explain the most relevant ones in the following:

- IoT Broker is specified as a lightweight and scalable middleware component that separates IoT applications from the underlying device installations.
- IoT Discovery is responsible for discovering the availability of context. In the CPaaS.io project, National Electric Code Configuration Management is used and enhanced as an implementation of the FIWARE IoT Discovery.
- IoT Knowledge Server adds semantic information into Next Generation Service Interfaces (NGSI) messages and enhances these NGSI messages with semantic reasoning. The IoT Knowledge Server component has an internal triple-store where NGSI (or other) ontologies are kept. It serves

semantic knowledge such as entity subtypes or supertypes and provides high-level access to the semantic ontologies via query/subscription functionalities.

- Data Context Broker is a specific middleware for brokering the communication between IoT data providers and IoT applications based on the NGSI standard as an open source generic enabler. It can provide various functionalities, such as queries pertaining to historical infor.mation, federation, or entity compositions.

- FogFlow Service Orchestrator[6] is a new component that has partially been developed within the CPaaS.io project. It is mainly used to dynamically generate, configure, and deploy data processing flows over clouds and edges in an optimized manner. The data processing flows are generated from a service topology based on a service requirement. This service requirement defines which service topology to trigger, which types of output data are expected, and which type of scheduling algorithm is preferred.

4.3 Federation of EU and Japan smart city platforms into CPaaS.io platform

As discussed, the two platform instantiations provide many common functions for smart cities. Also, some technologies are common to both platforms, including linked open data technologies such as RDF and SPARQL for semantic data management; RESTful APIs and the JavaScript Object Notation-LD data format for standard APIs; Open Identification Connect for Single-Sign-On; and Federation of Personal Authorization and Authentication.

But, because the u2 architecture and FIWARE are technologically quite different, a tightly coupled integration of implemented modules is not a realistic approach. Nor is such an approach desirable. While closely integrated systems may facilitate the development of smart-city applications, a smart city platform like CPaaS.io must be flexible and constantly adaptable to changing contexts; this can be achieved only with loosely coupled systems. The case holds particularly true when we target wide-area cooperation between smart cities in the EU and Japan. Thus, federation needs to be loosely coupled and will happen mostly at the semantic level (plus API-based data exchanges).

We are currently implementing realistic prototypes to show such a federation across distributed smart city platform instances. With this achieved, CPaaS.io will provide a solid platform on top of which cities can implement their smart city strategy, bringing innovation and quality of life to residents.

5 AIMING FOR FUTURE SMART CITIES

Today, there are many smart city activities in the world. Smart city services are very useful for improving the quality of residents' lives. But the most serious problem of these smart city service platforms is that they are mostly custom made, developed one by one for each city. This is because there is no general and practical smart city platform.

CPaaS.io platform is our answer for these general and practical smart city platforms which can support smart city services improving the residences' life quality. CPaaS.io is developing a technology platform, but for the deployment of smart city services, social and business platforms are also very important. In the future, the co-design of both technology platform and social platform will be necessary for smart cities.

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AUTHORS

NOBORU KOSHIZUKA is a professor and director of the Department of Applied Computer Science, The University of Tokyo, Japan. His research interests include ubiquitous computing, the Internet of Things, embedded systems, and open data. Koshizuka received a Ph.D. from The University of Tokyo, Japan, in 1994. He is a Member of the IEEE and ACM. Contact him at `noboru@koshizuka-lab.org`.

STEPHAN HALLER is a professor at the e-Government Institute of Bern University of Applied Sciences, teaching about e-business, enterprise architecture, and project management. His main research interests include the Internet of Things, linked open data, and the smart city. He has been involved in European research activities in this area for many years, serving in several expert groups of the European Commission and on scientific review boards as well as acquiring and successfully managing publicly funded research projects like CPaaS.io. He is a Member of the IEEE. Contact him at `stephan.haller@bfh.ch`.

KEN SAKAMURA is director of the Yokosuka Telecom Research Park Ubiquitous Networking Laboratory and a professor and dean of Faculty of Information Networking for Innovation and Design at Toyo University, Japan. He is the creator of the real-time operating system architecture TRON. For his achievements, Sakamura is the recipient of Japan's Prime Minister Award, the Japan Academy Prize, and the prestigious ITU150 award, among others. He was editor in chief of IEEE Micro and is a Fellow and Golden Core member of the IEEE Computer Society. Contact him at `ken@sakamura-lab.org`.

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