Comparative Study of Horizontal and Vertical Approaches to IoT Services for Smart Cities

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***Abstract*—Smart cities aim to address social issues in the community using Internet of Things (IoT). IoT has traditionally been used to address various challenges in different regions. Recently, efforts have focused on defining smart cities and addressing regional issues horizontally as they are often shared by other regions. There are two technological approaches to IoT services: the 'vertical approach,' which involves building unique IoT services tailored to regional characteristics, and the 'horizontal approach,' which enables new services by horizontally linking data collected in each region within City OS in the cloud. This paper categorizes technological approaches into three groups: 'service-specific type,' 'cloud-intensive type,' and 'edge-cloud cooperation type,' and compares their respective features.**

***Keywords*—smart city, Internet of Things (IoT), City OS, cloud/edge computing, horizontal approach, vertical approach**

I. Introduction

The implementation of Internet of Things (IoT) has sparked discussions about the development of smart cities through IoT technology [1]. The objective is to connect multiple sensors and surveillance cameras via IoT to monitor city conditions and address social issues [2]. Smart cities are a policy issue in many countries. The Japanese government's Cabinet Office has published a white paper on smart cities [3]. The paper emphasizes the significance of extending services to other regions using 'City OS (also known as Urban OS) [4]'.

IoT has been implemented in several areas to tackle various issues, some of which may be relevant to other regions. Currently, there is a drive to standardize the definition of a smart city and comprehensively address regional issues [5]. Section II outlines standardization efforts to clarify the definition of a smart city. Towards realizing a smart city, there are two technological approaches to IoT services: the 'vertical approach' and the 'horizontal approach [6].' The vertical approach involves building unique IoT services tailored to regional characteristics. The horizontal approach enables new services by linking data collected in each region within City OS in the cloud. The horizontal approach is divided into two categories: 'cloud-intensive type' and 'edge-cloud cooperation type.' 'Cloud-intensive type' aggregates IoT data in City OS in the cloud and links the data. However, this method may not be suitable for services that require immediate data processing, as the data is processed in the cloud [7]. To address this issue, a new approach called 'edge-cloud cooperation type' has been developed. This approach allows for the use of data both in the cloud and at the edge through edge computing [8], enabling a wide range of data usage with low latency.

This paper presents a survey of standardization efforts to clarify the definition of a smart city, as well as a categorization and comparison of the technological approaches to achieving a smart city.

II. Smart City Standardization Efforts

This section discusses the efforts of international standardization organizations to define a smart city. ISO TC 268 SC 1 [9], a subcommittee of the International Organization for Standardization (ISO) [10], actively discusses smart city standardization [11]. The oldest and most active of SC 1, WG 1 'Infrastructure metrics,' published ISO TS 37151 [12] 'Smart community infrastructures -- Principles and requirements for performance metrics' in May 2015. ISO/TS 37151 defines metrics for smart cities. Architectural model of a smart city, depicted in Fig. 1, comprises three tiers that represent the city's functions and activities. The service layer provides residents with various services that offer comfort, convenience, and safety. The facility layer provides services in specific locations, such as homes, offices, factories, or train stations. Facilities rely on urban infrastructure, such as energy, water, and transportation. Therefore, a layer for 'urban infrastructure' is defined below the facility layer. 'Urban infrastructure' refers to the infrastructure that covers the entire urban area of the country [13].

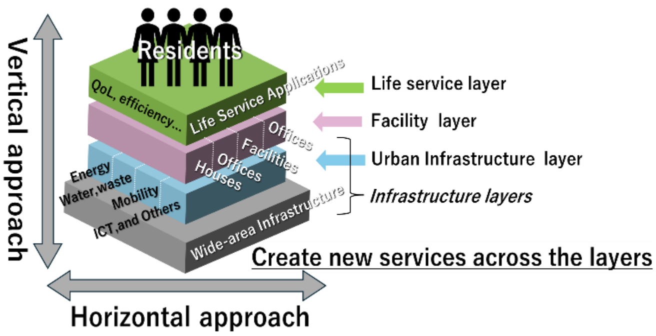

Fig. 1. The architectural model of smart city and approach [13].

Thus, the 'service layer' conventionally depends on the 'facility layer' and the 'urban infrastructure layer.' While there are no issues with these vertically dependent

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infrastructures for small-scale service deployment in a limited local area, as Fig. 1 shows, creating a smart city requires new services through horizontal coordination across other 'facility layers' and 'urban infrastructure layers' [14].

III. Technological Approaches to Smart Cities

To realize smart city, there are two technological approaches to IoT services: the 'vertical approach' and the 'horizontal approach.' The vertical approach involves building unique IoT services tailored to regional characteristics. The horizontal approach enables new services by linking data collected in each region within City OS in the cloud. The horizontal approach further divides into two categories: 'cloud-intensive type' and 'edge-cloud cooperation type.' The technological approach to achieving smart cities can be classified into three types: the vertical approach, which is 'service-specific type,' and the two horizontal approaches - 'cloud-intensive type' and 'edge-cloud cooperation type.' Fig. 2 illustrates technological approaches to smart cities. Section A explains the two horizontal approaches, while section B provides explains the vertical approach.

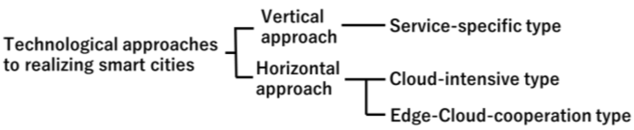

Fig. 2. Technological approaches to smart cities.

A. Horizontal Approach

The horizontal approach requires a shared infrastructure, like a computer operating system called City OS, to effectively provide IoT data and services. City OS standardizes data formats and interfaces, thereby facilitating the efficient sharing of data and the provision of services by cities [15]. This approach can achieve three specific objectives:

1) **Service portability:** Service providers can increase flexibility and accessibility by deploying their services in multiple regions. This is possible because services deployed in one region can quickly be deployed in another.
2) **Service diversification:** The above information simplifies adding or removing services.
3) **Service evolution:** Shared data enables referencing information from other regions, resulting in a more advanced service.

Next, 'cloud-intensive type' and 'edge-cloud cooperation type,' are explained.

1) *Cloud-intensive type*

Fig. 3 shows 'cloud-intensive type' of the horizontal approach to using City OS, which is the most common deployment method. IoT data generated in each region is aggregated to the City OS in the cloud for service provisioning. The IoT data from each region is domain-independent and can be deployed horizontally across City OSs and made available to different regions.

Fig. 3 shows how service X in region A is also provided in region C by City OS, and how service X is added to the existing service Y in region C. It also shows how the sharing of data between cities provides a more sophisticated service Z.

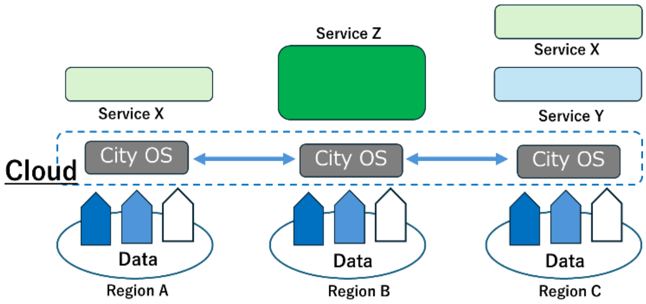

Fig. 3. Cloud-intensive type [15].

The advantages are that data can be shared widely, equipment can standardize, and capital and operating costs can reduce. However, the drawbacks are poor response performance for applications that require immediate feedback based on the data received and high operational costs when applied to localized applications such as smart communities. An alternative approach that addresses the shortcomings is 'edge-cloud cooperation type.'

2) *Edge-cloud cooperation type*

Fig. 4 illustrates 'edge-cloud cooperation type,' which addresses the issue of managing data in the cloud that may not be responsive enough for services requiring low latency and high responsiveness [7]. This approach enables comprehensive area data utilization in the cloud while allowing for low latency data utilization at the edge through edge computing [8]. As illustrated in Fig. 4, in 'edge-cloud coordination type,' IoT data obtained in each region aggregate to an IoT-gateway (IoT-GW) equipped with City OS at the network edge before being uploaded to the cloud. This enables low-latency services at the network edge via the IoT-GW. In both 'cloud-intensive type' and the method described here, when utilizing IoT services that share data across regions, the processing is conducted in the cloud.

Functions of the IoT-GW used in 'edge-cloud cooperation type' is shown in Fig. 5. The IoT-GW consists of three main functions, including 'Data Identification' and 'Data Aggregation,' in addition to the 'City OS.' Data identification is a function that identifies whether the data sent to the IoT-GW sends to either the city OS in the IoT-GW, the city OS in the cloud, or both. Data Aggregation is a function that temporarily aggregates data sent to the IoT-GW by IoT devices.

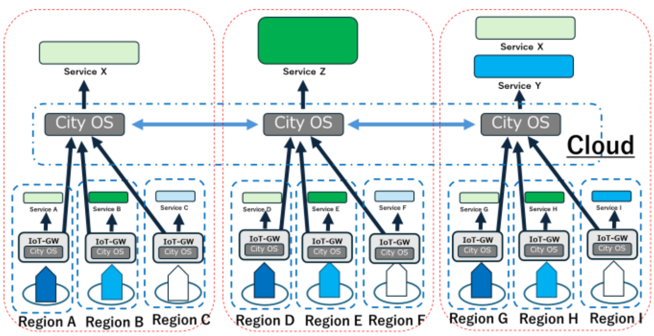

Fig. 4. Edge-cloud cooperation type.

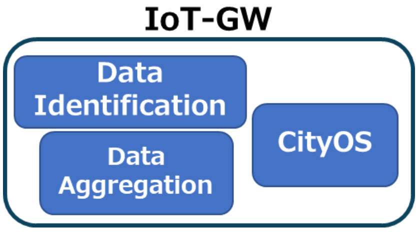

Fig. 5. Functions of IoT-GW.

B. Vertical Approach

1) Service-specific type

Fig. 6 displays 'service-specific type.' In a smart city, the vertical approach offers a specialized IoT service for a specific location. This allows the city to create customized IoT services tailored to its local characteristics without considering service transfer to other areas.

An illustrative example of 'service-specific type' is an IoT service designed for use in a construction site. As IoT services at construction sites handle data that only require for use within the construction site, it is possible to construct these services in a way that is specific to their intended purpose without having to consider the possibility of migration to other services.

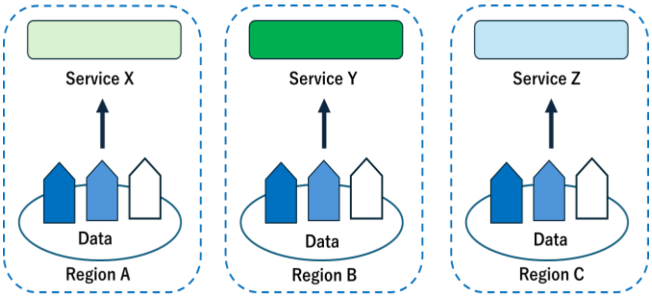

Fig. 6. Service-specific type.

IV. Comparative Study of Technological Approaches to Smart Cities

Section IV presents three technological approaches for smart cities and compares their effectiveness using the Analytic Hierarchy Process (AHP), a multi-criteria decision-making method. Section A provides an overview of AHP, followed by comparative studies in section B.

A. AHP Overview

AHP is a commonly used technique for Multi-Criteria Decision-Making (MCDM) [16]. AHP models the decision-making process hierarchically, using a 'goal - criteria - alternative' structure. The criteria are objectively assessed for importance and weighted using a statistical method. Each criterion is evaluated objectively to determine the superior alternative and by how much. The overall score is calculated by statistically combining the evaluation scores of the alternatives using the calculated weights of the criteria and the scores of the alternatives [17].

B. Results of a Comparative Study Using AHP

A comparison of three technological approaches will be conducted based on the AHP methodology described in section A. The study aims to assess practical technical approaches for Smart City applications based on evaluation criteria such as customizability, development cost, service migration, and low latency. In the comparative study, three alternatives will be considered: 'service-specific type', 'cloud-intensive type', and 'edge-cloud cooperation type. 'Fig. 7 compares the scores for each criterion of the alternatives using AHP. Fig. 8 also compares the scores of the alternatives for each criterion by AHP. The study presents three alternatives: 'edge-cloud cooperation type,' 'cloud intensive type,' and 'service-specific type'. Each type has its strengths. 'Edge-cloud cooperation type' has a better rating for low latency. At the same time, 'cloud-intensive type' is better for development cost, and 'service-specific type' is better for customizability. The study suggests that the horizontal approach is more effective than the vertical approach for service transitions. Therefore, for services that require low latency, 'edge-cloud cooperation type' is considered adequate. For situations where cost reduction is a priority, and low latency is not a concern, 'cloud-intensive type' recommends. If a system is required to address region-specific issues, 'service-specific type' is recommended.

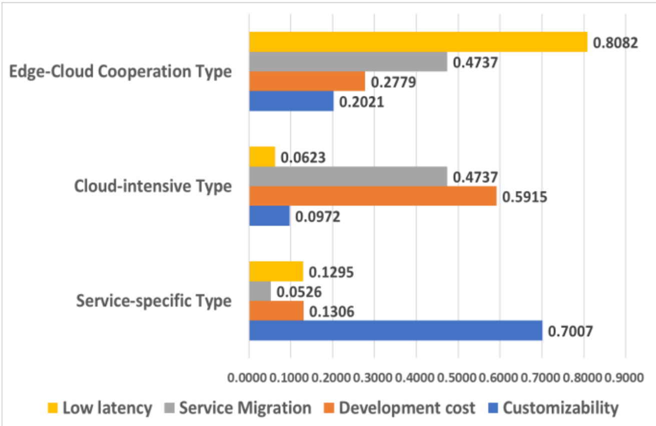

Fig. 7. Comparison of the scores for each criterion for each alternative by AHP.

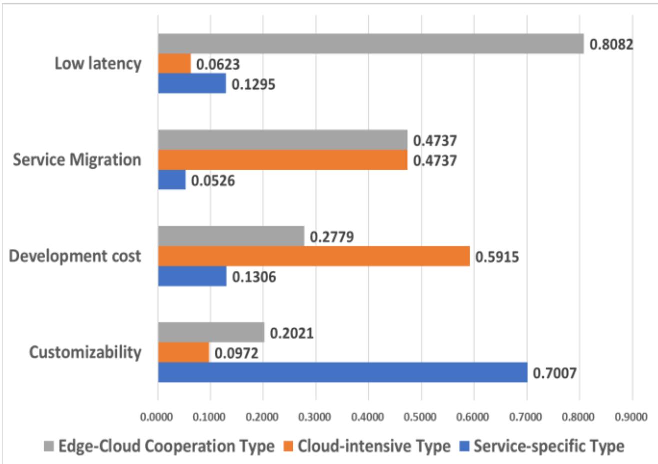

Fig. 8. Comparison of the scores of the alternatives for each criterion by AHP.

V. Policy on Selection of Approaches and Application Areas

Fig. 9 illustrates policy on selection of approaches based on the results of section IV-B. To determine the most effective approach, define the scope of the service. For small-scale services in a limited local area, use 'service-specific type.' However, when considering large-scale services across regions, it is essential to consider the need for low latency. If low latency is a requisite, the optimal solution would be 'edge-cloud coordination type.' Conversely, if low latency is not a concern, 'cloud-intensive type' would be the optimal solution.

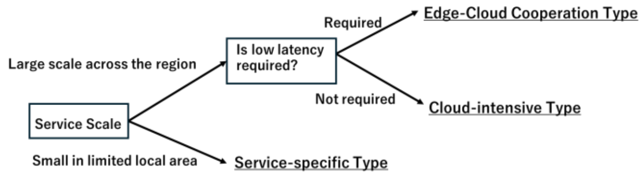

Fig. 9. Policy on selection of approaches.

Table 1 illustrates application areas of the three approaches. 'Edge-cloud coordination type' is practical in services where low-latency services mix with services that do not require low latency. One illustrative example of an application field is that of emergency information services. In this service, emergency information is rapidly disseminated to nearby areas via sirens and other devices at the edge, circumventing the cloud. Moreover, emergency information is transmitted to the cloud, which then disseminates the information to other areas. 'Cloud intensive type' is a practical approach for services that do not require low latency and need to collect information over a wide area. One illustrative example of an application field is weather information services. Weather information services do not require such low latency; instead, weather-related information must be collected over a wide area. 'Cloud-intensive type' allows for the sharing of assets with other regions, representing an effective strategy in terms of capital and operational investment. For example, new services can develop by leveraging weather information from disparate regions. 'Service-specific type' is adequate for services with a limited number of locations to serve. One illustrative example is the construction site patrolling robot service. This service uses a quadruped-like robot to patrol a construction site autonomously. The data collected by a robot patrolling a construction site represents an effective service because the services that can be provided using the data are limited, and the location (construction site) where the service is provided is also limited.

Table 1. Application areas of the three approaches

Approach	Practical Services	Practical Case
Edge-Cloud Cooperation Type	A mixture of services that require low latency and services that do not require low latency	Emergency Information Service
Cloud-intensive Type	Services that do not require low latency Services that require information to be collected over a wide area	Weather Information Service
Service-specific Type	Small scale service in limited local area	Patrol robot service for construction sites

VI. Conclusion

In this paper, the technological approaches to realize smart cities categorize into three types: service-specific type, cloud-intensive type, and edge-cloud coordination type, and the characteristics of each were compared and discussed. Based on these results, policy on selection of approaches and application areas was discussed.

In the future, more detailed verification conducts on the horizontal approach and the vertical approach to realize smart cities. This includes implementation studies with actual use cases. The verification concluded that the horizontal approach, 'edge-cloud coordination type,' is practical for services that are deployed horizontally and require low latency. It expects that the demand for industry-type services in smart cities will expand. Low latency is becoming increasingly important for services that require rapid response. In the future, the author intends to implement and evaluate an IoT-GW equipped with City OS functions to apply 'edge-cloud coordination type' practically. Therefore, it is essential to reduce the cost of IoT-GWs for large-scale deployment. The performance of low-end IoT-GWs is evaluated intending to reduce their cost. The performance evaluation demonstrates the computer resources required to process traffic for various services while meeting the required response performance. The author also argues that 'service-specific type' is also crucial in realizing smart cities. The reason for this approach is the persistence of demand to build unique IoT services that suit regional characteristics without considering the migration of services to other regions. To verify its usefulness, the author suggests building a system tailored to regional characteristics using actual use cases.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Shin-ichi Yamamoto was primarily responsible for the comparative study of the three approaches; Issa Yamanaka assisted Shin-ichi Yamamoto in the analysis of the data; Shin-ichi Yamamoto wrote the paper; Tetsuya Yokotani provided the primary guidance for the study; Koichi Ishibashi assisted in implementing the guidance provided by Tetsuya Yokotani; all authors had approved the final version.

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