엣지 컴퓨팅 기반 지능형 교통 시스템 오브 시스템즈의 품질 속성 평가를 위한 사례 분석*

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Towards the Quality Assessment of Intelligent Transportation System of Systems using Edge Computing

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Abstract

Along with the proliferation of the Internet of Things (IoT) and data volume, streaming the information between IoT devices and cloud data centers becomes inefficient, and cloud computing services have difficulties in providing quality services and satisfying important quality attributes. It has pushed the horizon of edge computing, to bring the computations at the edge of the network near end-users. However, designing complex System of Systems (SoS) with diverse IoT components is a non-trivial task due to several aspects to be considered such as hardware infrastructure, application components, users involved in the system, and cost concerns. The use of simulation tools can be a feasible way to experiment with the IoT systems, evaluate how the system will perform before the actual establishment of the system in the edge computing environments. We described the Intelligent Transportation System of Systems (ITSoS) as an example system, investigated the participating stakeholders along with user perspective quality factors to be considered before developing the simulation tools, and also compared existing simulation tools and quality metrics they support.

1. Introduction

An increase in data exchange and communication among heterogeneous Internet of Things (IoT) devices, has been generating massive data volumes and also maximizing the demand for data processing. In traditional cloud computing, all the data are sent to centralized servers where computations perform and return the computation results to the end devices, which can have a significant impact on the network in terms of cost, resources, as well as performance aspects [1]. IoT devices have poor connectivity and limited processing capabilities, and data generated from them have to travel over the network to the cloud for processing, which can be unsuitable for situations where the latency of milliseconds can pose serious threats. Thus, researchers have focused on the edge computing paradigm that encompasses the data processing and storage to perform at the network edges close to the end-users, fastening the response time and providing better bandwidth availability of IoT systems.

When designing an IoT system using edge computing, IoT system architects need to consider several aspects, including the entities involved in the hardware infrastructure, application software components, and locations to deploy the hardware and software components. Besides, they need to ensure that the developed systems can satisfy the stakeholders' needs and desired quality factors. In addition, developing the edge computing infrastructure is complex and requires high financial investment. One practical way to address these challenges, and to design the system in an easy and configurable manner would be the use of simulation platforms. However, existing simulation tools still haven't supported a wider variety of quality measurements and the use-case analysis are not sufficient as well. Additionally, IoT applications are considered as system of systems (SoS) in which SoS consists of various operationally independent component systems. One such application is intelligent transportation system of systems (ITSoS). In this paper, we study the use case of ITSoS using edge-cloud collaboration architecture, identify stakeholders involved in ITSoS and their needs regarding quality attributes. In the end, we compare existing edge computing simulators that can be used for designing ITSoS and supported quality metrics.

2. Related Work

Much research in recent years has studied the integration of IoT and edge computing and simulators for edge computing based IoT systems. Muccini et al. [2] reviewed the IoT architectural styles and quality attributes that can satisfy the IoT architectures, such as security, interoperability, and performance. But they did not study the qualities for IoT systems using edge

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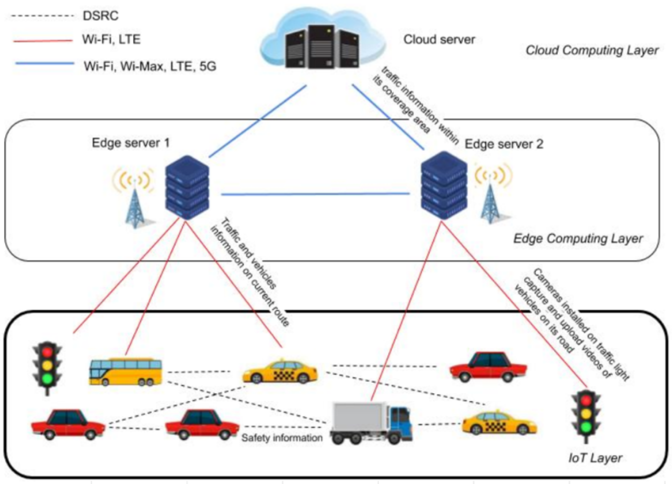

Figure 1: ITSoS using edge-cloud collaboration architecture

Table 1: Stakeholders and quality factors

Stakeholders	Quality factors for ITSoS
User in vehicles	- Latency of the services - Security and confidentiality of their personal data
City Administrator	- Latency of the services - Resource utilization of the services - Reliability of the system
Police officer	- Latency of the service when updating information to control centers and receiving report from the end-users
Weather control center	- Latency of the service when updating weather information
Emergency Service Center	- Latency of the service when updating information to control centers and receiving emergency information from the end-users
Server Manager	- Resource utilization of the services - Reliability of the system - System availability of the system

computing and respective quality metrics. The comparisons of quality metrics addressed by the cloud computing simulators are studied in [3]. Gharian et al. [4] conducted a study of some of the existing simulation platforms used to test, validate and assess the performance of Public Transport Control Systems (PTCS). However, they did not investigate the PTCS using edge computing, and their analysis was based on the ability to integrate the infrastructure, vehicles, and travelers' behavior, and did not consider quality attributes. There remains a need to identify the user perspective quality factors based on the users involved in IoT systems and simulation tools that can analyze those quality parameters of IoT systems. In this paper, we comprehensively studied them by providing the use case of an intelligent transportation system.

3. Use Case of Edge Computing for Intelligent Transportation System of Systems

Intelligent Transportation System of Systems (ITSoS) is an integrated system composed of heterogeneous, and independent constituent systems (CS) such as vehicles, people, roadside units, central control centers, which are interacting and collaborating each other to achieve the goal that cannot be achieved by a single CS [5]. Figure 1 illustrates the architecture of edge computing based ITSoS. IoT layer will include smart devices like surveillance cameras, traffic lights, application units equipped within vehicles. Roadside units, micro base stations, and edge servers are deployed at the edge layer for exchanging data between vehicles and infrastructures through the vehicle to infrastructure(V2I) communication. The cloud layer can be considered as the central control center that manages the region or nationwide traffic flow.

For example, to achieve the goal of "avoiding road congestion", vehicles will share the vehicle information in terms of their distance, position, direction, speed, etc. And then, edge servers will gather real time information from vehicles, and road cameras installed in a respective coverage area but also data from nearby edge servers. It will then perform local data processing to classify the congestion level of roads and compute the optimal route suggestion to avoid the traffic, to re-route vehicles by signaling the traffic lights. Cloud servers will have the city scale traffic information, storing an enormous amount of traffic data to make system-wide decisions, perform traffic flow prediction and analysis. Some applications of the ITSoS include real-time traffic control systems, automatic highway systems, accident management systems, video surveillance systems, etc.

3.1. Stakeholders (Users) Involved in ITSoS and User Perspective Quality Factors

We studied ISO/IEC 25010 model [6] and identified the quality factors applicable in edge computing-based systems. Table 1 shows the participating stakeholders in ITSoS and quality factors that they concern about when they utilize the edge computing based ITSoS system or services. Description of the quality factors along with quality metrics, goals of each stakeholder, how they use or participate in the ITSoS, and why they require those quality factors are described in detail here. (https://github.com/hannahthwe/Edge-Computing-in-ITSoS)

3.2. Comparison of Edge Computing Simulation Tools and Quality Metrics

To measure the quality factors that users concern about in ITSoS identified in Table 1, we firstly referred ISO/IEC 25023 model [7] and extracted the quality metrics that can measure those quality factors. We also included other metrics frequently used in the literature, such as processing latency, network latency, and energy consumption. In the end, we evaluate the existing edge computing simulation tools based on the quality metrics they support, as shown in Table 2.

Table 2. Comparison of simulation tools and supported quality metrics

	iFogSim	Edge Cloud Sim	IoT Sim	IoT Sim-Edge
Response Time	✓	✓	-	✓
Processing latency	✓	✓	✓	✓
Network latency	-	✓	✓	✓
Bandwidth utilization	✓	✓	✓	✓
Energy consumption	✓	-	-	✓
Transaction processing capacity	-	✓	-	✓
System availability	-	-	-	-
Fault tolerance	-	-	-	-
Data Confidentiality	-	-	-	-

iFogSim simulator can model and simulate IoT, fog, and edge computing including edge devices, cloud data centers, and network links, and can measure performance metrics like latency, energy consumption, network congestion, and also operational costs [8]. EdgeCloudSim provides an edge computing simulation environment and can analyze the performance of edge computing systems, such as the bandwidth utilization and transmission latency on the delay of service requests [9]. IoTSim simulator [10] can model IoT applications and can process large amounts of sensor data. It also allows the simulation of the performance of IoT applications such as network communication and delays between data storage and processing virtual machines. Additionally, the IoTSim-Edge simulator [11] captures the behavior of heterogeneous IoT and edge computing infrastructure and supports performance testing and validation of edge computing configurations. It shows its effectiveness using different test cases, including capacity planning for roadside units in ITS. It also supports the ability to access different performance metrics such as time behavior and resource utilization. As we can see in table 2, while most of the existing tools support the quality metrics like latency and bandwidth utilization, only a few can measure the transaction processing capacity and energy consumption of IoT components.

4. Conclusion and Discussion

The deployment of an edge-computing architecture for IoT systems has become popular and use of simulation tools can help the IoT architects test and understand the system before establishing the real-world IoT and edge computing infrastructure. In this paper, we investigated the use case of edge computing for the intelligent transportation system and identified the system components, stakeholders, their quality-related concerns, and quality metrics that require to be considered before developing an edge computing simulation tool. Besides, we compared existing simulation tools and quality metrics they support as well. Indeed, building the edge computing simulators that can measure the quality parameters of systems and services such as performance, system availability, and security is not a trivial task, and no simulation tool can yet support those metrics. To sum up, this paper can be a guide for the researchers to comprehend the edge computing paradigm highlighting that there is still an opportunity for them to take the research effort to develop the tools by elaborating remaining quality metrics like system availability, fault tolerance, and security-related metrics in the future. As our future work, we aim to develop a simulation tool that can check and measure the user perspective quality factors that have not been addressed yet.

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