Proceedings of the Seventh International Conference on Research in Intelligent and Computing in Engineering pp. 37–41
DOI: 10.15439/2022R38
ISSN 2300-5963 ACSIS, Vol. 33

An Edge Computing Collaboration Solution for Internet of Vehicles

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Abstract **- The advent of 5^{th} generation communication systems (5G) in the early 21^{st} century has realized real-time Internet of Things applications. 5G has capable of providing network services with extremely-high throughput and extremely low delay and allows a huge device number to connect together based on Internet infrastructure, forming the Internet of Things (IoT). In recent years, IoT has been applied in a variety of fields serving humans, such as smart cities, smart agriculture, e-healthcare, smart education, military, and IoT ecosystems. One of the main challenges of IoT applications is computing solutions to reduce service response times. In this study, we propose an Edge Computing Collaboration Solution for the Internet of Vehicles (IoV). Our solution proposes a small database that allows edge computing servers of IoVs to store each other's information. When the mobile end-users move to the new edge servers' managed coverage, properties related to the EC service are exchanged between the edge servers. The results have shown that our proposed solution improves significantly service response time, by up to 10-20%, compared to the existing solutions.**

Index Terms**—5G, Internet of Things, Edge Computing, Internet of Vehicles (IoVs).**

I. INTRODUCTION

Smart devices are becoming more popular and necessary tools in modern society. The communication systems between network devices are increasingly diverse and complex in solutions and technologies. The 5^{th} generation networks, also known as $5G$, are attractive and topical study topics [1]. The $5G$ network enables the delivery of services with ultra-high throughput and ultra-low latency and allows hundreds of billions of mobile devices to connect. 5G realizes the concept of the IoT and forms emerging applications serving humans in smart cities, smart agriculture, smart healthcare, and other smart ecosystems [2].

According to Cisco's forecast, the number of connected IoT devices to the Internet will be over 500 billion by 2030 [3]. As a result, these devices will generate huge amounts of data. Traditional data processing models and methods are infeasible [4]. For recent decades, cloud computing (CC) is the dominant technology in all fields. CC has proven outstanding capability and ability by providing robust computing services with high reliability. One limitation of CC is high latency time, so it is unachievable to real-time IoT solutions [5]. To address this problem, edge computing (EC) was proposed. EC brings the abilities of the cloud closer to end-users, reducing service response times and realizing real-time IoT applications [6], as shown in **Fig. 1**.

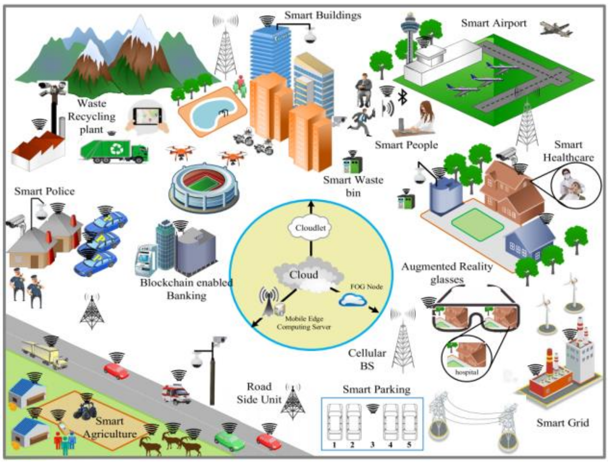

Fig. 1. An Illustration of EC-based Smart Cities [7].

In recent, IoT-based smart city applications have been focused on research. Smart cities provide a wide range of convenient services for citizens, including smart energy management, smart healthcare, intelligent transportation systems and other utility services. It can be said that smart cities are the combination of the internet infrastructure, Internet of things and big data processing to provide citizens with increasingly superior smart utilities [7].

In this work, we introduce a collaboration solution between EC servers to improve performance and reduce latency for real-time IoVs applications in smart cities. The rest of this paper is organized as follows: in Section 2, we present related works. The proposed solution is introduced in Section 3. Section 4 presents simulation results and analysis. The conclusion and open research issues is presented in Section 5.

II. RELATED WORKS

In recent, smart cities is one of the emerging fields that have attracted great attention from the research community in both industry and academia. The concept of smart cities is very diverse. According to [8], smart cities are divided into six components, including *citizens*, *economy*, *governance*, *transportation*, *environment* and *living*, see **Fig. 2**.

Aiming to present a full picture of the recent smart cities applications based on IoT, we perform a literature review of proposals in three years in this area.

- In the field of citizens, proposals focus on aspects to provide a more comfortable living for humans. Specifically, the authors have proposed a framework to enhance security [9], biometrics [10] and sports activities [11].

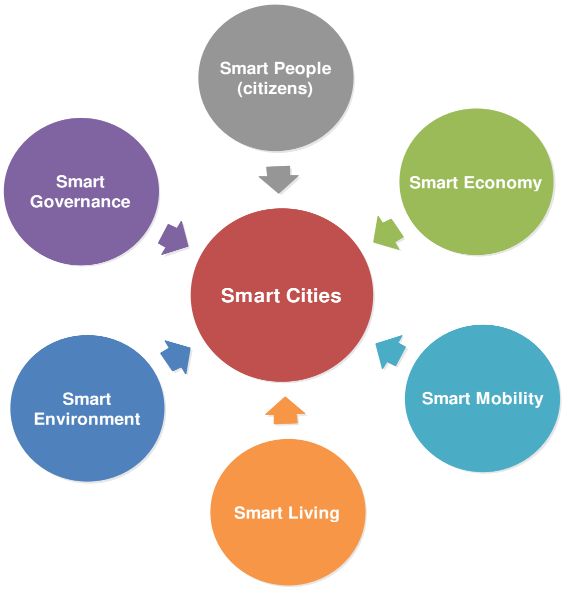

Fig. 2. The key components of smart cities.

- In the field of the economy, solutions focus on aspects to develop a sustainable economy, including, improving seaport operations [12], charging solutions for IoE vehicles and EC-based resource allocation solutions [13].
- In the field of mobility, studies focus on solving the challenges of intelligent transportation systems, such as resources allocation solutions for IoE vehicles [14], optimal routing and estimation for vehicles [15].
- In the field of environments, proposals focus on solutions to provide a green environment for residents, such as optimal routing based on the quality of air metrics [16], smart irrigation solutions [17] and green environmental management architectures [18].
- In the field of smart living, studies focus on solutions to improve the life quality of residents, such as travel recommendations [19], resident control and monitoring [20] and healthcare [21].
- In the field of governance, proposals focus on proposing governance solutions, such as infrastructure management [22], complex event solutions [23] and voting solutions [24].

The surveyed results have shown that the vision of smart cities still has many challenges. The proposals are still in the primitive stage and are limited to each specific sector. More research and proposals with integrated solutions need to be employed in this field. Studies have also demonstrated that the heart of smart cities is the citizens. Therefore, the awareness, applicability and adoption of new technologies, as well as the active participation of residents, are major problems. However, in our opinion, although there are still many challenges, smart cities will be an inevitable development trend in the near future.

III. THE PROPOSED SOLUTION

A. *Motivation*

We consider an IoV system based on edge computing for smart cities. This system connects vehicles, IoT devices, sensors, applications and people based on the Internet to provide smart utility services for citizens, as described in Section II. Specifically, sensors collect information. According to the convention architecture, the information is obtained and processed at other layers such as EC and CC [25] based on connections within their coverage. Consequently, the information is sent to the edge servers, see **Fig. 3**. However, the IoVs in smart cities, vehicles are often mobile. This leads to disconnection to the edge server when vehicles move out of the edge server's coverage. Then, vehicles have to establish a connection to another edge server and re-request its edge services. When a vehicle connects to a new edge server, the services that were performed at the old edge server are discarded and re-requested at the new edge server. As a result, response times and system resources will increase. With the huge vehicle numbers in smart cities, the system resource and power consumption will be huge. This is the motivation for us to do this research.

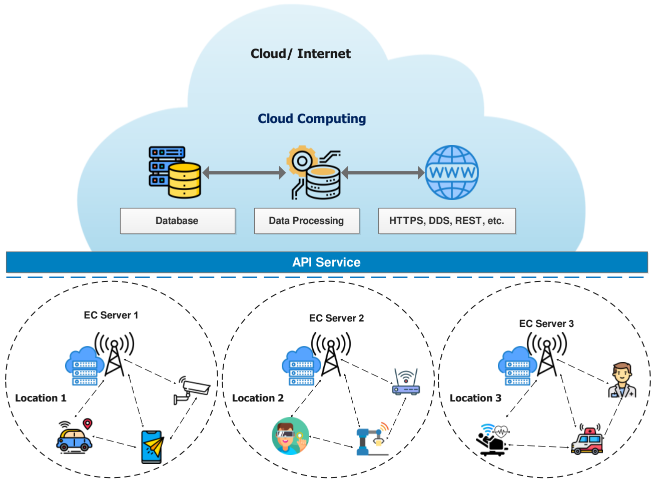

Fig. 3 The EC-based IoT architecture for smart cities.

B. *Proposed Network Architecture*

In existing architecture, the system consists of three layers: things, edge and cloud layers, as presented in **Fig. 3**. It should be recalled that, in a network system, the two basic transactions are searching and routing. These transactions are invoked to serve service requests derived from the Things layer with objectives including minimal service response time, saving energy and system resource consumption. In the proposed architecture, we establish an information map between the EC centres, as shown in **Fig. 4**.

The information map is defined as follows: An information map is a small database to store properties and services that the EC servers have provided. When the end-user moves from

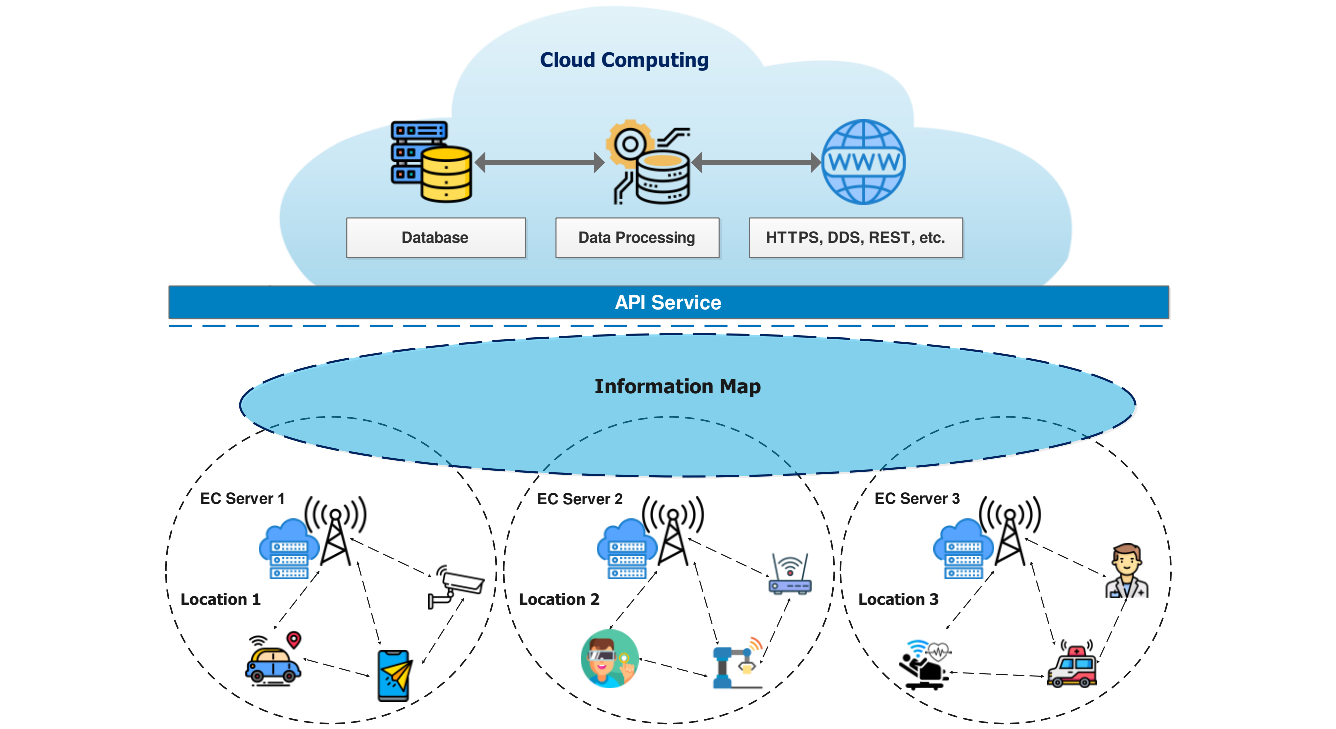

Fig. 4 The proposed EC-based IoT architecture for smart cities.

one coverage to another, an EC server, instead of having to launch a search process on a cloud to fulfil service requests that were served previously or other executed EC servers, now, EC servers simply searches within the information map. Consequently, service response times, energy and system resource consumption will be significantly reduced. The proposed architecture is presented in Fig. 4.

C. *The effectiveness of our solution*

In this study, we define some mathematical symbols as follows:

- Symbol n is the number of mobile nodes that must roam while is service request progressing.
- Symbol T and T' are the service request and response time at each layer, respectively. T and T' are the same value in all coverage.
- Symbol T_{S1}, T_{S2}, and T_{S3} are the searching time at the things, edge and cloud layers, respectively.
- Symbol T_{R1}, T_{R2} and T_{R3} are the routing time at the things, edge and cloud layers, respectively
- Symbol T'_{S1}, T'_{S2}, and T'_{S3} are the routing time to return results at things, edge and cloud layers, respectively.

When the mobile node moves in coverage, the service response time cost of a transaction is determined as follows:

$$T = \sum_{i=1}^{n}(T_{S1} + T_{S2} + T_{S3}) + \sum_{i=1}^{n}(T_{R1} + T_{R2} + T_{R3}) \quad (1)$$

$$T_1' = T_2' = \sum_{i=1}^{n}(T_{R1}' + T_{R2}' + T_{R3}') \quad (2)$$

$$T = (T_1 + T_1') \quad (3)$$

Suppose that, while the mobile end-user initializes a service request, the system will perform the searching and routing transactions at things, edge and cloud, respectively, to respond to this request. In-while, the mobile end-user moves to new coverage. In the traditional architecture, allsearching and routing transactions will be re-performed on new coverage. Consequently, time and energy consumption have been determined as follows,

$$T = 2 \times (T_1 + T_1') \quad (4)$$

In our proposed model, to determine the service response time, T_1 and T'_1 values are still defined in Eq. (1) and (2), respectively. However, when a mobile user roams to new coverage, due to the support of information maps, mobile users are still able to use the searched results that have been performed in the old coverage. Therefore, T_2 and T'_2 values are determined according to Eq. (5) and Eq. (6).

$$T_2 = \sum_{i=1}^{n}(T_{S1} + T_{S2}) + \sum_{i=1}^{n}(T_{R1} + T_{R2}) \quad (5)$$

$$T_2' = \sum_{i=1}^{n}(T_{R1}' + T_{R2}') \quad (6)$$

IV. SIMULATION AND ANALYSIS

Aiming to clarify the effectiveness of the proposed solution, we set up an EC-based IoT system consisting of 1.000 mobile end-user nodes. We have assumed that the percentage of nodes roaming in while transactions are processing in a range $\lambda_{max} \in [10 - 25]\%$. Moreover, to focus on clarifying the efficiency of the solution, we have also assumed that the costs of routing and searching for different coverage are the same and represented by numbers.

- *The traditional solution*: apply Eq. (1)-(4).

- *The proposed solution*: T_1 and T'_1 values still applied Eq. (1)-(4), while T_2 and T'_2 values applied Eq. (5)-(6).

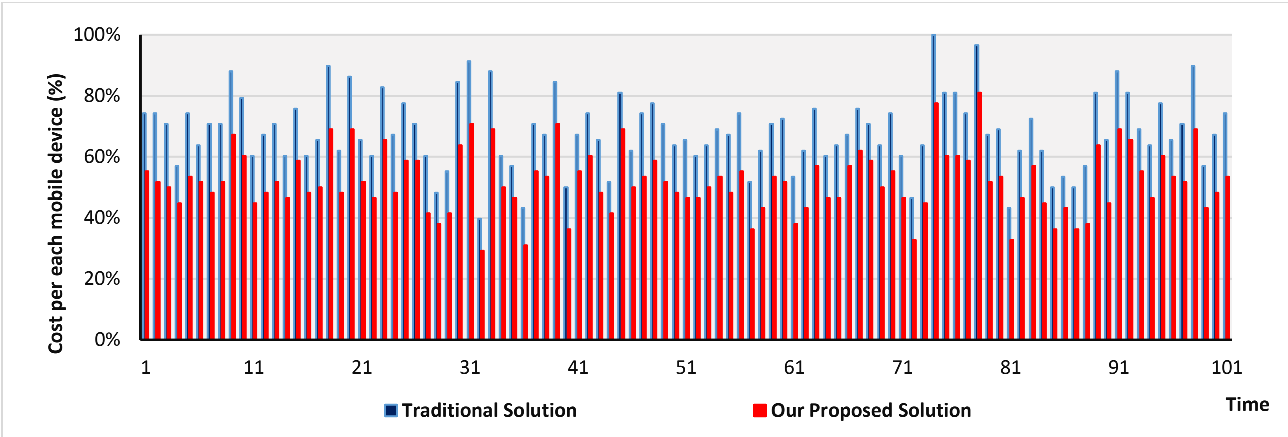

Fig. 5. The cost-effectiveness of the proposed method per each device.

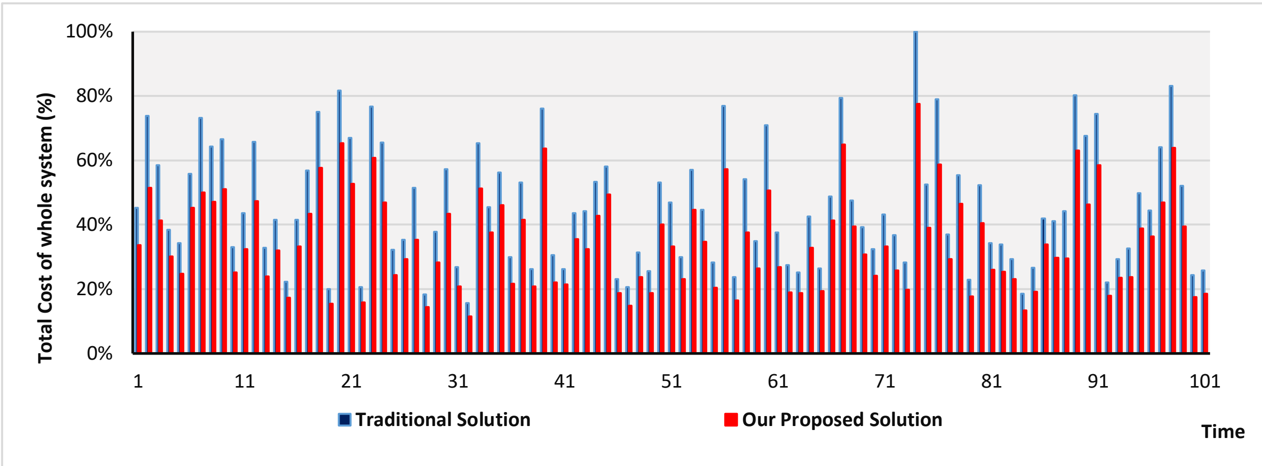

Fig. 6. The cost-effectiveness of the proposed method for the whole system.

Fig. 5 presents a performance comparison of two solutions in terms of the average service response time per service request at the things layer. The simulation results have shown that the proposed solution reduces the service response time by $[10 - 20]\%$ compared to the existing solutions.

Fig. 6 presents a performance comparison in terms of the service response time of the whole system. The results have shown that the new solution significantly reduces the response time of all requests from vehicles compared to the existing solution. The effectiveness of this solution is becoming more apparent as the number of increased roaming service requests corresponds to an increase in mobile vehicle numbers.

Besides the effectiveness of reducing service response time. In another aspect, the energy consumption of the whole system will also be significantly improved. This problem will be shown in our future studies.

V. Conclusion and Open Issues

In this study, we focus on studying a collaboration solution between EC servers to reduce response time for real-time IoVs applications in smart cities. Our proposed solution operates at the application layer between edge computing servers by establishing a small data map to store properties of edge services that are performed by edge servers. This solution is very effective in reducing response time and enhancing the performance of IoVs applications in smart cities. The results have indicated that our solution outperforms compared to existing algorithms. From the privacy and security perspectives, the proposed information map must be against attacks or fake information maps. The problems will be presented by us in future works.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

We have conducted the research, analyzed the data, and performed simulations together. All authors had approved the final version.

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