Autonomous Driving Vehicle Controlling Network Using Dynamic Migrated Edge Computer Function

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ABSTRACT
Autonomous driving vehicle control by edge computer network having very short response time has been proposed. Each vehicle has an agent program on the edge and automatically moved to adjacent edge computer following to the vehicle movement. On the edge computer, the agent program is processing with other vehicles' agents in a cyber network. We employ triple redundancy and majority rule to achieve high-reliability and less than 10 ms control latency try to be guaranteed. In addition, each vehicle has an IoT sensor including fine-GPS, so all precious position and speed of the vehicle can be monitored. We constructed the autonomous driving experimental course, the autonomous driving vehicle, and the edge computer system with the center cloud and tested in the campus test bed. According to the vehicle movement, network orchestrator setup a new optical path automatically and send the agent program to the adjacent target edge computer. This orchestration function is newly proposed application triggered dynamic optical network. In this presentation, I will show the detailed experimental results. This architecture and experimental results can be applied to the future smart and connected community.

Keywords: 5G network, edge computing, IoT, autonomous driving, cyber physical, live migration.

1. INTRODUCTION
Cloud services, autonomous driving vehicles (ADVs), smart houses, and the Internet of Things (IoT) will use optical access/metro networks to create, store, and process massive amount of data in cloud data centers (DCs). The cloud DC architecture will be changed from a centralized mega-DC cloud to distributed and interconnected small computers such as edge computers and micro-DCs [1]. Optical interconnection eases the bandwidth and distance restrictions among distributed edge computers [2].

The smart and connected community (S&CC) network proposal uses optical interconnection to linked-objects, humans, and applications to a network that offers sophisticated processing functions [3]. S&CC requires that user application and processing functions be provided with collaborated each other. Because each user application has supported by cloud and computers. In addition, low latency and trustworthy edge computing are needed [4][5]. And also the center cloud has a huge processing power with sophisticated artificial intelligence (AI) functions [6]. Our solution is to dynamically combine resources through optical interconnection [7][8][9].

This paper introduces user application network/cloud resource coordination for the future distributed cloud network era. Especially, ADV is an important user application which need to be supported by network. For ADV, an agent program operating at an edge computer move to an adjacent edge computer flowing to moving the vehicle [10]. This migration must be guarantee less than 10 ms control latency between the vehicle and the edge computer. The network architecture and techniques proposed herein will be used in future optically interconnected cloud networks.

2. AUTONOMOUS DRIVING VEHICLE IN CONNECTED COMMUNITY
There are two types of approach for realizing ADV. First is a standalone approach. A robot drives a vehicle with sophisticated AI functions. There are many sensors such as a camera, a millimeter wave sensor, and a light detection and ranging (LIDAR) system to detect obstacles and other cars. In vehicle processors calculate and control vehicle automatically in standalone. Vehicle communicated to the devices such as traffic signals and other cars.

Second approach is a connected car approach in the S&CC network. A cyber physical system (CPS) is a base concept for this approach. In CPS, a cyber network has a control function and all controls are done in cyber space. A physical vehicle is just controlled from the cyber network like a simple remote control car.

All vehicle control program called an agent program is operated at the edge computer as shown in Fig 1. In the edge computer, the agent program communicates each other, and controls priority, and decides position, speed, and actions.

An example of the sophisticated control among agents at edge computers is described. Figure 2 shows the intersection control method at the edge computer. There are four cars at the intersection. One from bottom, A1 and three from right side, B1, B2, and B3. Ordinary, A1 and B1 is alternately go into the intersection. However, from “Maximized Social Welfare (MSW)” approach is different. Under the MSW, sum of waiting time for all cars must be minimized.
\[
\sum_{i=1}^{n_1} D_{A_i} + \sum_{i=1}^{n_2} D_{B_i} = \text{Delay total}
\] (1)

where \(n_1\) and \(n_2\) are number of waiting cars. MSW means minimized formula (1). Of course, max delay of \(D_{A_i}\) or \(D_{B_i}\) is restriction. That means, the worst case, \(A_i\) wait maximum 10 cars and go into the intersection.

Another example of CPS control is priority control based an economical incentive mechanism. Red car \(B_3\) is high priority. If \(A_1\) is stopped for \(B_3\) in cyber network, \(B_3\) give small incentives to \(A_1\) like bit-coin. In other words, cyber network is not only control but also market place for control. Such sophisticated control car be possible in CPS is new research issues for social sciences.

![Figure 1. Agent : Edge computer for autonomous driving vehicle.](image1)

![Figure 2. Intersection control method from the social science approach.](image2)

3. APPLICATION-TRIGGERED DYNAMIC NETWORK CONFIGURATION BASED ON OPTICAL NETWORK

We describe here an application-triggered integrated network/computing resource architecture for S&CC. The architecture is designed to suit several typical S&CC applications such as networked robots, ADVs, and big data analysis. Figure 4 shows typical applications for S&CC such as network robots, IoT, and ADVs.

ADV's are key S&CC application; their cloud processing function must offer trustworthiness and supporting high mobility (see Fig. 3). Because vehicles move very rapidly, they need real-time response from edge computers. Fifth-generation (5G) wireless access meets the requirement for quick access, but the ability to transfer or migration of processing functions is also very important. We call this “horizontal integration” Details will be described in next here after. In addition, we demonstrated some experimental system in the articles [11], [12], and [13].

Trustworthy control is needed. To meet these requirements, we proposed the dynamic edge processing system with horizontal virtual machine (VM) live migration, as shown in Fig. 4. For the first step, we use VM, but container or process level migration will be used. For our next experiment, we have designed the edge computing with triple redundancy and majority rule for achieving trustworthiness.

This is because moving vehicles sometimes lose the connection to the controller VM. Moreover, live migration demands a migration period and thus a control interrupt in the ADV program. Triple redundancy with majority rule can ensure trustworthy control under such communication and control interruptions.

![Figure 3. Proposed network architecture based on center cloud-centric and local logical mesh.](image3)

![Figure 4. Horizontal VM live migration for supporting trustworthy connection.](image4)
Efficient horizontal VM live migration which is realized across edge devices (Micro-DCs or edge computers) is a key to realizing this concept. Figure 5(a) shows horizontal live migration across the current metro/access network using layer-3 (i.e., IP) networking. This conventional approach was adopted because there is little need to transfer huge amounts of data among edge computers; most applications such as smart homes and networked robots are static. Therefore, the conventional approach to copying data between edge computers is to use the layer-3 function located in the metro IP routers. This IP-based routing is characterized by long delay times.

Our solution was to propose and test lower-layer cut-through among optical network units in the Japanese national project called Elastic Lambda Access Network (EλAN) [14][15][16]. Using EλAN, live migration via a lower network layer can be realized as shown in Fig. 5(b). This dynamic function mobility is a new requirement for the S&CC network.

4. EXPERIMENT AND TEST-BED
The proposed network architecture based on agent migration among edge computer is shown in Fig. 6. Center Cloud is sophisticated functions such as AI and logging. For the edge computer, dynamic and logical mesh network is constructed. Logical mesh means between edges, dynamic optical path can be setup. This is not real fiber mesh but Layer-1 cut-thought among edge computers. Using optical circuit path, each edge computer connected each other directly by optical path (L1).

We demonstrated agent (VM) migration through optical path as shown in Fig. 7. Application (Vehicle) triggered network, create optical path and migrate control program automatically. In this demonstration, we use 400 Gbps reconfigurable optical add/drop multiplexers (ROADMs) with a multi-layer orchestrator. The vehicle control program is set at local server or Alaxala Network’s reconfigurable service module (RSM) as edge computers. Following to the vehicle movement, all control function is migrated among edge computers.

We try to grantee less than 10 ms control latency from the edge computer. In addition, during agent migration, there are no data losses. However, small communication interruption is caused as shown in Fig. 8(c). To avoid this interruption, we will employ triple redundant and/or majority rule. This is our next step research target.
5. CONCLUSION

Future networks must carry multiple new services to support the smart society. Each service has different characteristics and places different requirements on the network in terms of data amount and delay tolerance. This paper introduces the concept of application-triggered automatic network configuration coordinated with processing functions and network resources. To create more flexible and dynamic networks, the migration of VMs and functions must be possible. We describe horizontal VM migration for AD-cars. Edge computers are switched to follow the vehicle, keeping response times under 10 ms while providing triple redundancy for trustworthy control. We also tested at small testbed system for an ADV in Keio University. Using this automated CPS control network, future smart and convenient connected community can be possible.

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REFERENCES