Remote Vehicular Control Network Test Platform

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Abstract. In this paper, architecture is proposed to test remote control network for low speed vehicle remote driving. By using 4G cellular network access to the cloud service platform, the platform is easy to deployed in common commercial networks. A control signal transmit experiment is executed in the commercial network crossing one more thousand miles; the performance show that the common 4G cellular and backbone networks can support the real-time signal transmit for low speed vehicle. Video latency is tested using different cameras, and the MOS is defined to measure how difficult to drive a remote vehicle under certain video latency.

Keywords: Remote drive · Vehicular video · Cloud computing · UDP · TCP · User experience

1 Introduction

Some new approaches are proposed to improve network performance in new wireless communication services [1–3]. These new approaches are used to improve the quality of service (QoS) for end user [4–7]. Through analyzing the end user behavior, the traffic flow model is able to be built [8–10]. Based on these models, the traffic can be described accurately and be used to build test scenarios [11, 12]. On the other hand, some traffic reconstructions methods are proposed to improve network efficiency [13–15], such as effective capacity [16–18], network utilization [19, 20], spectral-efficiency [21–23] and energy-efficiency [24–26]. Besides the object index, the subject user experience is critical index for commercial network [27–30]. Traffic prediction helps to improve the quality of end user experience [31–33]. However, the remote driving poses challenges to QoS request and objective quality measurement. At present, the self-driving technology cannot handle the vehicle operation under all working conditions. Considering complex scenarios and critical safe requirement, it is unlikely that self-driving will be deployed in common commercial scenarios. Combined with mobile communication technology, a few remote drivers can handle the complex situation of a large number of vehicles, which is expected to achieve man-machine cooperation driving. Many low-speed and medium-speed unmanned vehicle with fixed working scope and simple environment may take the lead because of their small risks.

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C-V2X Communication is an emerging 5G scenario. 3GPP requires the 5G remote driving communication performance obtain 99.999% reliability, 25 Mb/s upload bandwidth, and 1 Mb/s download, and 20 ms delay. 5G-based self driving standards are rapidly moving towards commercial deployment [34, 35]. With the large-scale commercial deployment of mobile interconnection services based on cloud platform, IMT-2020 develops a small-scale field environment testing method of "Cellular + Vehicle Networking" (C-V2X). Although 5G cellular network and edge computing greatly reduce end-to-end responding time [36], most of remote driving system only can be deployed in LAN scenarios [37]. There is a lack of research on remote driving test for common commercial network. The cost of developing remote driving parallel management and control system is very high, the test in commercial network is necessary [38, 39].

Aiming at the scenario of remote parallel management and control low-speed vehicle, this paper proposes the test method in cellular scenario. The paper is divided into five sections. The related work is given in section two. Test system and experiment are illustrated in section tree and section four respectively. We conclude in section five.

2 Related Work

In January 21, 2019, Ericsson, Jiangsu Mobile, Qingdao Hui Tuo, and Intel test remote driving accessing to 5G cellular network in Intelligent Vehicle Research and Development Center located in Suzhou Changshu. Current researches focus on simplifying complex physical systems and building artificial systems, analyzing the behavior of physical systems, effectively managing the operation of complex systems by parallel execution between physical systems and artificial system [40]. By keeping the consistency between the real system and the artificial system, not only accurate control can be carried out, but also the whole life cycle of the equipment can be analyzed and predicted [41]. On the basis of collecting a large amount of historical data, a simulation environment can be constructed in the artificial system to predict and correct the consequences of operation, which is helpful to improve the capability of large-scale remote control system [42, 43]. To reduce the cost, it is expected that a common cloud platform and common commercial cellular access network will be employed into remote control system. The artificial system will be deployed in cloud platform. The physical system will linked to artificial system via cellular network. The latency constraint between physical system and artificial system is critical for remote driving. Different from conventional user experience measurement, the drivers' experience is related to its task. Therefore, the remote driving experience should measure how difficult to control the real vehicle.

3 Architecture of Remote Driving

3.1 Network Architecture

In order to control remote vehicles in real-time, we design architecture as in Fig. 1:

(1) The vehicles collect video and send to the control center through a common cloud platform. If the vehicle fails for its task, the human driver requires the real-time video from cloud platform.

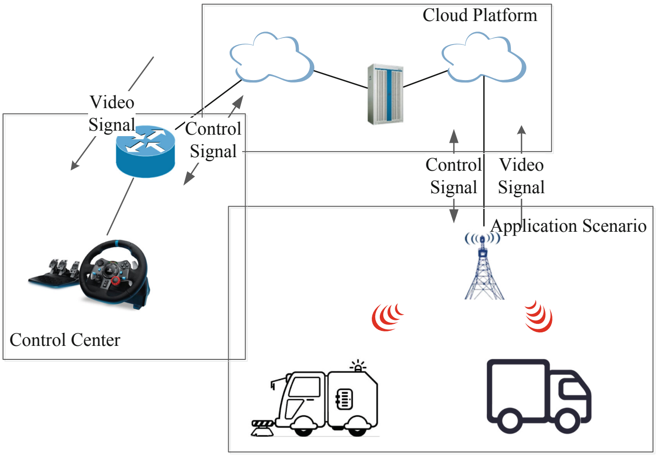

Fig. 1. Architecture diagram of the vehicle network.

(2) The drivers' operations on G29 are collected by machines; the machine encodes the operations into control signal within packet. The cloud server sends signals and some necessary parameters between control center and vehicles.
(3) The system transmits the control signal defined frequency; therefore it is easy to check whether the signal arrives in time. Since the vehicles response the control center with an acknowledge packet, the test system can know the round trip latency.

3.2 Instruction Collection Design

We adopt the G29 wheel equipment to collect the human driver operations. The Table 1 presents the control signal transmitting to remote vehicle.

Table 1. The operation parameters.

Operation	Type	Length	Upper bound	Down bound
Wheel-turn	float	64 bit	100	0
Shifter-gear	float	64 bit	− 1, 1, 2, 3, 4, 5, 6	
Pedals-gas	float	64 bit	1	0
Pedals-brake	float	64 bit	1	0
Pedals-clutch	float	64 bit	1	0

As a real-time system, the overdue control signals are useless; therefore we adopt UDP protocol. The control center sends control signals to the cloud server; the server sends the signal to the vehicle according to identification number. The vehicle response with an acknowledgement signal; the round trip latency is recorded.

3.3 Video Latency Test

In order to reduce the video transmission time, we set up the following camera network topology to test the video transmission time of multiple cameras. The architecture is illustrated in Fig. 2.

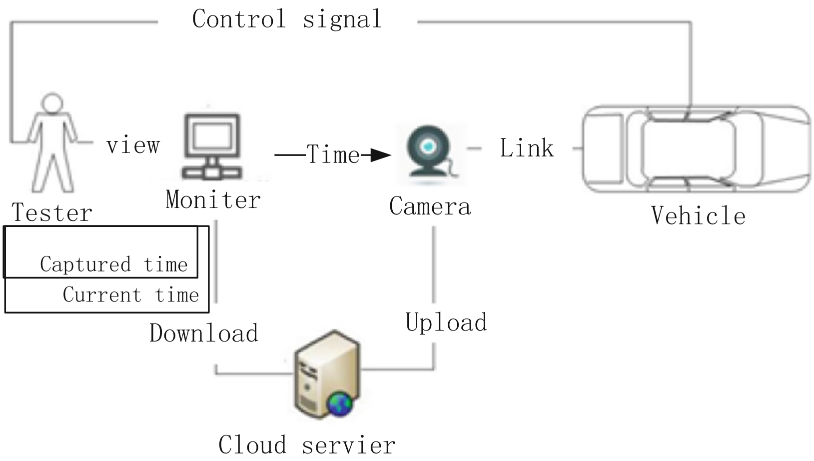

Fig. 2. Video test diagram.

(1) The camera, router, terminal server, and client are connected as in Fig. 2. For accurate test, the camera captures the picture of monitor and sends the captured picture to the terminal server. Note that the picture carries the time showing in the monitor.

(2) Both current time and captured time show on the monitor. The whole latency including encode latency, decode latency, and transmission latency is obtained by comparing the two time.

4 Experiment

4.1 Remote Video Test

We tested a total of 6 cameras and collected certain data at the same time. The following Table 2 shows the models and parameters of the 6 cameras:

During the test, the respective private protocols were used. In the LAN environment, the video delay was calculated. After testing, we get the following picture (Fig. 3).

In this experiment, the Raspberry Pi 3B used RTMP protocol, and the rest used its own private protocol. In order to obtain a more accurate delay, we used the method of comparing the recorded time on the video with the real time to obtain the delay difference. According to experiment results, we can conclude that under 4G conditions, the optimal delay time is Raspberry Pi 3B. The maximum value is 372 ms and the minimum value

Table 2. Video test parameters.

Model	Frame
CS-C6TC-32WFR	15
TL-IPC42EW-4	15
CS-C6CN-1C2WFR	15
TP7C-E625	10
360 Small droplets	15
Raspberry Pi 3B	10

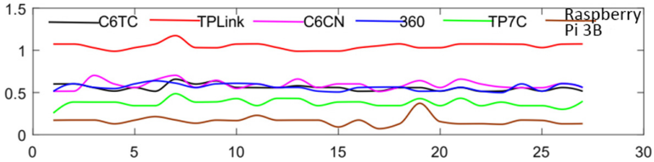

Fig. 3. Video test result. (MOS reduce VS. Test time, the MOS computation reference to the method in [1]).

is only 71 ms. The stability of the delay is generally within the acceptable range. For the Raspberry Pi 3B, the delay of the TP7C is also in the acceptable range, with an average delay of 375 ms and a maximum of 486 ms. Therefore, according to the MOS value of the experimental results, under the conditions of 4G and Raspberry Pi 3B video delay, it can basically meet the requests of driving video transmission of low-speed remote vehicles.

However, the movement effect cannot be well simulated under the conditions of static indoor conditions. Therefore, another data transmission experiment is executed in the moving vehicle. We chose the following different sites for testing, corridors, roads, campuses and suburb.

Table 3. Video test results.

Condition	Average(s)	Maximum(s)	Minimum(s)	Standard deviation
Corridor	0.267	0.364	0.216	0.04126
Way	0.275	0.651	0.16	0.11048
Campus	0.255	0.304	0.175	0.03082
Suburb	0.262	0.304	0.217	0.02374

Experimental results are presented in Table 3. According to the experimental results, under the condition of good network conditions, the transmission of delay is basically stable, which can basically meet the video conditions of low-speed remote driving.

The camera used in this experiment has a resolution of 720 * 1280. From an average point of view, the delay on campus is lower than that tested elsewhere; the transmission delay on roads is too high and at the same time the lowest. In comparison, the stability of roads is worse, and the stability in remote areas is the highest.

Experimental summary: through this mobile test, the effect of a moving object on a 4G network is realistically simulated. In different local environments, the data is not very different. Generally speaking, the overall situation of delay is in an acceptable range. At the same time, it can be compared with the static delay data, observe the differences, and imagine the experimental conclusions. Not only that, using mobile delay data as reference data for driverless driving is more contrastive and convincing.

4.2 Control Experience Test

Since the transmission of video is bound to a certain delay under the condition of 4G, in order to investigate the difficulty level of driving a remote vehicle with different speeds and certain delay, we propose experiment to measure the driver experience using driving game with certain video latency and speed.

In this experiment, for the sake of safety, we use the video game instead of the actual vehicle. The game picture by camera, to the server, and then by the monitor get to video data (data is compared with the real vehicle at this time there is a delay). At this time, the experimenter controlled the vehicle according to the acquired experimental data. A total of five test people were selected for this experiment, and data acquisition was performed multiple times. During the time delay control, we use multiple cameras to increase the delay. Note that this method introduces some fluctuations.

In the experiment environment, we adopt Learn Che Bao as simulation software. Cameras are Raspberry Pi 3B and Tencent Class, For Raspberry Pi, we still choose 10 frames with a resolution of 720 * 1280, and Tencent Class uses default parameters. During the experimental process, we firstly shoot through the Raspberry Pi camera to get the minimum average delay, then we adopt Tencent class camera, which has higher transmit delay than Raspberry, to increase latency, and then increase the latency by using the Tencent Class recording screen that show the video recorded by Raspberry Pi 3B. Through this method, we can increase certain latency by increasing cameras before the end monitor. And the drivers give their subject feeling about how difficult to control the car as the latency increases. The lower MOS means more difficulty.

The experimental results are shown in Fig. 4. The results obtained in the figure show that under the condition of low delay, the vehicle can be basically controlled under the condition of 4G under the condition of 40 km/h. With the latency higher than 500 ms, according to the feedback of the driver, the vehicle barely is controlled. With latency lower than 500 ms and speed higher than 40 km/h, it is also in an uncontrollable state. According to the results in the game, after the MOS value is roughly below 3, the car accident rate in the test data reaches 81.58%. With the latency less than 40 km/h, the MOS is high. Therefore, we conclude that in 4G conditions, low-speed long-distance driving can be satisfied.

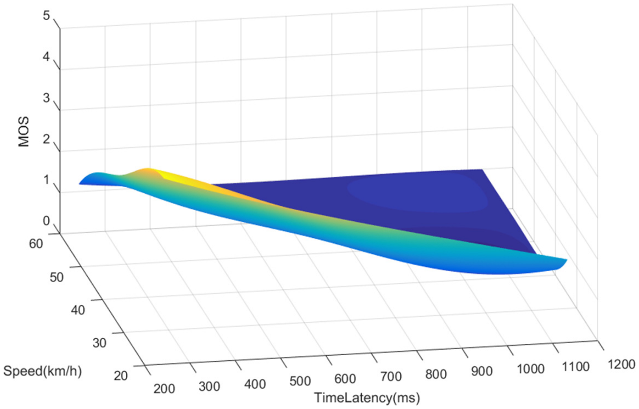

Fig. 4. Video test result.

4.3 Remote Control Signal

We deploy the vehicle and control center in the city of Xuzhou of China. The cloud platform is in Guangzhou locating one more thousand miles apart from Xuzhou. The vehicles access to backbone network via wired link and cellular network respectively. The round-trip latency is presented in Fig. 5 and Fig. 6.

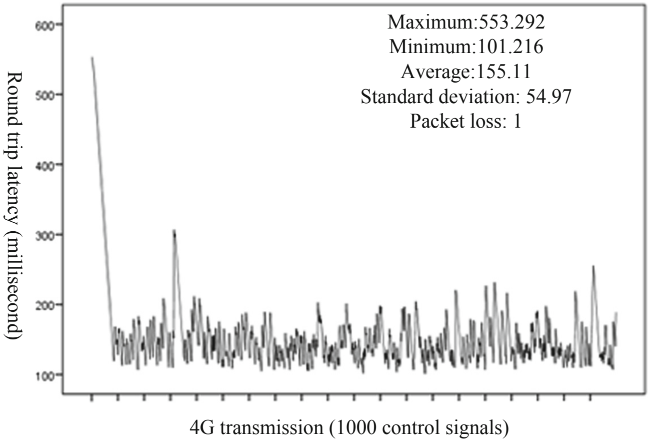

Fig. 5. 4G transmission.

Figure 5 and 6 shows the data transmission time of two access models. The number of tests was 1000. Analyzing the chart, the bottleneck of data transmission time is still air interface. We can expect a significant improvement in 5G network which provide the low latency and high reliability air interface communication.

The 155 ms average round trip latency can support remote control of some low speed special vehicles.

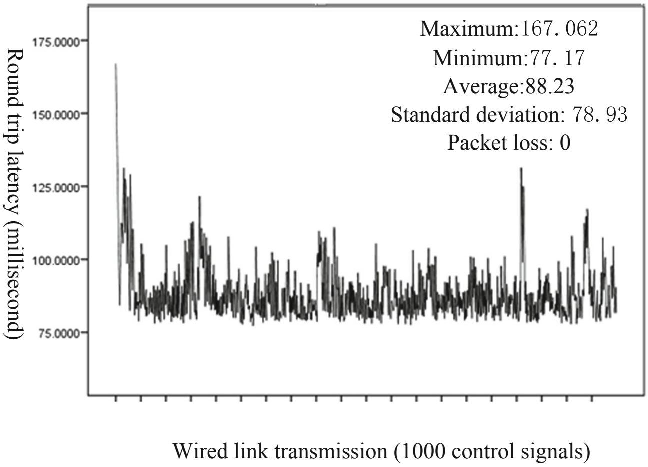

Fig. 6. Wired transmission.

5 Summary

Based on the characteristics of remote control vehicle, we propose test method based on common cloud platform and commercial cellular networks. The UDP is adopted to transmit control signal. With well designed test platform, the driver's subjective experience is able to be measured. The experiment results show that the 4G networks can support remote control for low speed vehicle. And the relationship between video latency and controllable speed is presented.

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