CU-CVIS Test Bed: A Test Bed of Cooperative Vehicle-Infrastructure System in Chang’an University

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ABSTRACT: With the rapid development of information technology, there is an increasing interest in connected vehicle and related technology. Compared to the large number of simulation studies on connected vehicle, there appeared to be few empirical studies on the performance of networks and applications due to the lack of suitable hardware facilities. Therefore, Chang’an University started to build a cooperative vehicle-infrastructure system test bed with different types of ITS scenarios and communication systems such as 4G-LTE and VANET (Vehicular Ad Hoc Network), which was called CU-CVIS test bed and located in its Weishui campus. In this paper, the architecture and detailed functions of CU-CVIS test bed are presented. Firstly, some important connected vehicle test beds in the world are introduced. Next, based on the demand of applications on connected vehicle, details of CU-CVIS test bed, such as architecture of the test bed, construction of 4G-LTE and DSRC communication systems and result of performance test, are described. The characteristics of CU-CVIS test bed are also presented. Finally, the vision and developing strategy of the test bed in the future are discussed with opportunities and challenges. It can be concluded that CU-CVIS can simulate various connected vehicle scenarios with reliable heterogeneous vehicular network and support future empirical study on connected vehicle and other related technologies.

INTRODUCTION

With the development of wireless communication technology, the concept of CVIS is proposed. CVIS can be used for proactively control and comprehensive service for vehicles via information sharing and extraction by vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) wireless information interaction. In essence, CVIS aims to lower the information asymmetry among different traffic elements including participants and managements in order to implement “omniscience” for all traffic elements, so as to improve safety, mobility and reduce energy use and emissions. There have been a great number of studies on CVIS relevant wireless communications, system application and traffic management mode. Most of the past researches merely relied on theoretical analysis and simulation because of the lack of experimental conditions. However, there were still a small amount of empirical studies based on nonstandard test bed. That probably indicates uncontrollable systematic errors. For example, test track in [1] was a 1200ft long oval-shaped track with 500ft long and 100ft wide. And the surroundings were not mentioned. In [2], the test vehicles were driven along different roads in the camp of Beihang University circularly, but the potential impact on test results due to test environment was not discussed in detail. It is difficult to reproduce the result of these empirical studies and may reduce the persuasion. In [3], urban road in Taicang, China,
was used as test track. However, the test time could not be guaranteed because its function of public facilities. CVIS is an application-oriented system with matters of engineering. That means scientific empirical study is an important methodology from theoretical research to practical application and standardized test bed is needed urgently.

Considering the demands of industry and scientific research, combined with the coordinated development of China's wireless communication and traffic characteristics, Chang’an university built CVIS test bed in Weishui campus. There are three parts in this article. The first part is an introduction of major test beds in the globe. Mcity in Michigan and GoMentum in California, United States and Smart Highway in South Korea will be introduced respectively. CU-CVIS test bed will be illustrated by three layers in the second part, including application layer, network layer and management layer. In the third part, discussion about the problems found during the construction and operation of the test bed will be held, as well as the prospection for the future development and challenges.

EXISTING TEST BEDS

At present, there are several test beds with the aim of realizing CVIS and other advanced traffic technology related to ITS. In this article, three of the representative test beds are selected, which are Mcity of Mobility Transformation Center in the University of Michigan, United States, Connected Vehicles(CV) Autonomous Vehicles(AV) Program, GoMentum Station of CCTA (Contra Costa Transportation Authority), California, United States, and the National R&D Projected, Smart Highway in Gyeonggi province, South Korea.

Mcity of University of Michigan is the most well-known CVIS test bed in the world, located in Ann Arbor, Michigan, United States. Mcity covers an area of 32 acres, various roads and traffic conditions in the urban scenarios including intersections, traffic signs and signals, pavement, simulated architecture and street lights are set in the test bed. Mcity is co-constructed by Mobility Transformation Center of the University of Michigan, the government and enterprises. It was put into operation in July 20th, 2015 officially, which becomes a good demonstration for the organization mode of CVIS test bed. The main application purpose of Mcity is to "develop and implement an advanced system of connected and automated vehicles". In addition, Ford has run an autonomous vehicle test in Mcity. However, there are still some issues in Mcity, such as small area and a lack of highway scenario. It emphasizes on connected and automated vehicle, which probably leads to a poor support of systemic and comprehensive CVIS application and management test [4].

GoMentum of CCTA, was built on a former Navy weapon station in Concord, California, covering an area of 5000 acres. It is the largest CVIS test bed in the world, which has 2100 acres available for test. The CV part of GoMentum is an extension of USDOT (United States Department of Transportation)’s CV program, with targets of improving safety, mobility and reducing energy use and emissions. A variety of traffic scenarios can be utilized to enable real world test in GoMentum test bed, including over 20 miles of paved roadways, a 7-mile long spine road for high speed testing, two 1400-ft. long tunnels, freeway underpasses and variable roadway geometrics, railroad crossings and tracks. CCTA believes that in the new era, traffic congestion will not be solved by
increasing road construction investment, but with implying the application of technology such as CV/AV. Utilizing the technologies and creativity of Bay Area, GoMentum will provide test ground for CVIS, as well as promote the local economy and create employment opportunities. Supports from local government encourage the subsequent development of the test bed. It is still in the early construction stage and urban roadway grids, buildings and other intelligent infrastructures have not been put into use. More facilities and experimental conditions remain to be further improved [5].

Smart Highway is developed, constructed and managed by Korea Ministry of Land, Transport and Maritime (MLTM). It is located in Yeoju Test Road (Central Region Expressway, 257.1km from Masan) with the length of 7.7km, built from October, 2007. Road technologies, traffic technologies and automobile technologies are researched in the test bed. Network connection of Smart Highway is VANET based on WAVE and Wi-Fi. At the same time, 5.8GHz ETC (Electronic Toll Collection) dedicated short-range communication system in accordance with Chinese standard has been introduced. Compared with the other two test beds, scenario of Smart Highway is relatively simple, and there is only highway scenario for tests and studies about CVIS [6].

INTRODUCTION OF CU-CVIS TEST BED

![Figure 1. The satellite imagery and indoor, outdoor facilities of CU-CVIS test bed.](image)

CU-CVIS test bed is located in Weishui campus of Chang’an University, which covers an area of 282,000 square meters (about 70 acres). It is equipped with a 2.4 kilometers high-speed circular test road with 2 lanes and an extra 1.1 kilometers straight 4-lane test track. 4 kinds of pavement (asphalt, concrete, bricks, and dirt) are also built in the test bed. It is a comprehensive and closed environment for testing various CVIS and other ITS applications. The satellite imagery and indoor, outdoor facilities are shown in FIG. 1. There are three different function layers in CU-CVIS test bed including application layer,
network layer and management layer as shown in FIG. 2. Every layer is designed and built in a modular way to ensure the compatibility between different modules and expandability for new functions.

Figure 2. Architecture of CU-CVIS test bed.

Application layer includes smart roadside facilities and connected and automated vehicle module. Smart roadside facilities can be divided into two modules, which are information awareness module and information releasing module. Information awareness module is equipped with sensor of weather, image and magnetic loop which support acquisition of real-time traffic and other related information to investigate and validate. Information releasing module, including LED information boards, traffic signs and signals, is applied to release traffic management strategies and other related information. Connected and automated Vehicle module equipped with an automated vehicle and 4 connected vehicles, as shown in FIG. 3. Li-DARs, radars, graphics and other sensors are set up to the automated vehicle with power supply and computing devices. Connected vehicles are equipped with heterogeneous network access terminals and on-board computers.

Figure 3. Connected vehicles and automated vehicle of CU-CVIS test bed.
The network layer in CU-CVIS test bed is the major part of construction. Considering that the architecture of bearer network of connected vehicle has not been decided, heterogeneous network facilities are organized in the test bed. The mature and promising wireless networks for connected vehicle are introduced to the test bed and organize heterogeneous network geared to the needs of personalized network performance requirements. VANET and 4G-LTE platform have been constructed and tested.

VANET devices are provided by China Genvict Tech Co. Ltd. The terminal WAVEBOX1001 utilizes a high performance ARM chip, NXP SAF5100, as the processor, which is based on IEEE 802.11p and IEEE 1609 protocol stacks. Working frequency of it is 5.850GHz-5.925GHz with a data rate up to 27Mb/s. With the default transmitting power, the maximal communication distance is 300 meters. The MK5 series VANET products provide by Cohda Wireless Co. Ltd, Australia is on going, too.

The 4G-LTE system is a private cellular wireless network operating on the frequency of 1.88-1.9GHz with TD-LTE protocol, which is constructed by China Datang Mobile Co., Ltd. It comprises of eNodeB base station, Customer Premise Equipment (CPE) terminals, Evolved Packet Core (EPC), server cluster and switches. The LTE platform has 4 directional antennas with the maximal transmission power of 60 watts, which enables the full wireless signal coverage of the whole test bed. The LTE platform is divided into 4 cells, and each cell can accommodate up to 200 user equipments (UEs). The unitary maximum throughput of the LTE system is up to 20Mb/s uplink and 80Mb/s downlink. The LTE platform is based on time division duplex, which is more suitable in traffic scenarios than frequency division duplex, i.e., FDD, because more information is uploaded. Measurements of the performance empirical study of VANET and 4G-LTE is shown in FIG. 4. Test was taken in collision avoidance (CA) scenario and traffic message broadcasting (TMB) scenario, which are typical scenarios for both V2V and V2I communication. Performance was acquired from the device which is set on the vehicle in different speeds and in line with expectations. The result shows that VANET has better performance on PLR and average RTT delay than LTE. And it makes VANET more capable for traffic safety application than LTE. The RTT delay of LTE in collision avoidance scenario seems unacceptable because all the information has to be relayed by the base station.

![Figure 4. Measured performance of VANET and LTE in collision avoidance and traffic message broadcasting scenario.](image-url)
Furthermore, the installation of EUHT (Enhanced Ultra-High Throughput) platform provided by Newfront Corp., Ltd and LTE-V platform provided by HUAWEI Tech Corp., Ltd., is in progress now. EUHT is the standard for wireless communication protocol of DSRC (Dedicated Short-Range Communication) in China. Its field performance of transmission bandwidth and Doppler Effect resistance is superior to almost all other wireless communication modes to our knowledge. It has been to pilot assembly on the high-speed rail and provided HD video transmission at speed of 350km/h. LTE-V supports terminal-to-terminal communication through LTE PHY layer technologies and improves the efficiency of MAC layer in existing VANET by avoiding channel interference, which is realized through allocating time-frequency resources by base stations. It can be utilized not only in the area with coverage of LTE signal but also in non-signaled scene.

Management layer provides interface for artificial control and management information to the other parts of test bed. At present, the test bed is equipped with monitoring system, data collecting system, storage system and processing system. Real-time floating vehicle information in Xi’an provided by transportation management department is inserted, laying the foundation for traffic data processing and visualization display. Now we are going to increase the computing abilities and local network application servers for further CVIS communication and application test.

Compared with other existing test beds, CU-CVIS test bed has the following characteristics. Firstly, CU-CVIS test bed is the most suitable test bed for testing the switching strategy of heterogeneous network and related technologies, because, in our knowledge, more varieties of vehicular networks are equipped than any other test bed, including VANET, LTE, LTE-V, EUHT and Wi-Fi. Secondly, much attention is paid to the design of management layer, therefore advanced intelligent traffic management modes can be tested in our test bed. At last, modularized structure enriched CU-CVIS test bed’s compatibility with new devices and technologies so that not only connected vehicle applications but also connected vehicle equipment can be tested.

OPEN ISSUES AND FUTURE WORK

Opportunities

China is confronted by serious problems resulted by traffic congestion, traffic accidents and air pollution, thus, there is a strong desire to change this situation through technology. Meanwhile, Chinese are more likely to accept and enjoy wireless communication and related technologies compared with other countries due to the successful mobile internet applications. All above built a positive foundation for the promotion and development of CVIS in China. Besides, efforts contributed by developed countries, scientific institutions and enterprises and supports given by the powerful Chinese government will promote the application of advanced technology. It is clear that China has a great potential in developing CVIS. In addition, the construction and utilization of test bed will become a significant procedure in applying advanced technology into real product. So there is a golden opportunity for CU-CVIS test bed.
Development of sample application

Test beds are not only test grounds for professionals, but also platforms to display new technologies for the general public and government as a huge change to urban management, traffic management and people’s daily life will be brought by CVIS. Therefore, emphasis should be laid on the development of sample applications. At present, CU-CVIS team has started a program about platoon, CACC related technologies, and we hope it could be introduced to transportation industry at first as the sample application of CVIS technology.

Establishment of certification standards

A certification standard is to be established to assess communication modes and application processes, as the test bed is a necessary transformation phase of CVIS from research to practice.

From close test to open test

In China, there are many closed tests for CVIS [2,7-8]. In the future, with the development of CVIS technology, the demand from closed to open test will be more and more urgent. Closed test is convenient and simple compared to real-world test which needs permissions and cooperation from variety management departments. It is also a severe challenge for us.

CONCLUSIONS

With the rapid development of CVIS, there is a trend from theory research to empirical study. Therefore, we constructed CU-CVIS test bed. In this paper, three major CVIS test beds are introduced and analyzed, followed by an illustration of application layer, communication layer and management layer of CU-CVIS test bed. The test result of communication system and characteristics of it indicate that the test bed meets the requirement of test for CVIS and other related technologies. Open issues and future work are discussed at last. In the future, our emphasis will be shifted to the development of sample application and the establishment of standard for test. CU-CVIS can support many kinds of CVIS application tests in heterogeneous network and will play an important role in promoting CVIS in China.

ACKNOWLEDGEMENTS

This work was supported and made possible by National Natural Science Foundation of China (Grant No.51278058), Application of Basic Research Project for National Ministry of Transport (Grant No.2015319812060) and the Fundamental Research Funds for the Central Universities (Grant No. 310824165024).

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