AutowareV2X: Enabling V2X Communication and Collective Perception for Autonomous Driving

Yu Asabe
The University of Tokyo
yuasabe@hongo.wide.ad.jp

Ehsan Javanmardi
The University of Tokyo
ejavanmardi@g.ecc.u-tokyo.ac.jp

Jin Nakazato
The University of Tokyo
jin-nakazato@g.ecc.u-tokyo.ac.jp

Manabu Tsukada
The University of Tokyo
tsukada@hongo.wide.ad.jp

Hiroshi Esaki
The University of Tokyo
hiroshi@wide.ad.jp

ABSTRACT

For cooperative intelligent transport systems (C-ITS), autonomous vehicles utilize vehicle-to-everything (V2X) communication to share critical information, enabling cooperatively enhanced environmental awareness and decision-making. We propose AutowareV2X, an implementation of a V2X communication module that is integrated into the autonomous driving (AD) software, Autoware. AutowareV2X provides external connectivity to the entire AD stack, enabling the end-to-end experimentation and evaluation of connected autonomous vehicles (CAV).

KEYWORDS

Cooperative ITS, V2X, Cooperative Perception

1 INTRODUCTION

For cooperative intelligent transport systems (C-ITS), vehicle-to-everything (V2X) communication is utilized to realize connected autonomous vehicles (CAVs), allowing them to share critical information with each other in order to enhance environmental awareness and cooperative decision-making. This additional layer of previously exclusive information allows CAVs to achieve a level of safety and efficiency that is impossible by stand-alone autonomous vehicles (AVs) or human drivers. Several communication protocols have been standardized, such as the ITS Forum message in Japan, the Cooperative Awareness Message (CAM) [8] in Europe, and the Basic Safety Message (BSM) in the United States. These messages are advertised in the 760MHz band in Japan, and the 5.8-5.9GHz band in Europe and the US.

To cooperatively improve environmental awareness, discussions for new standards such as the Collective Perception Service (CPS) [9] are underway, allowing CAVs to share their perception information. AutoC2X [3] enables Cooperative Awareness Messages (CAM) [8]-based cooperative perception by integrating the ITS communication protocol stack called OpenC2X [6] into the autonomous driving (AD) stack, Autoware [5]. This implementation, however, uses an outdated version of Autoware, and the communication stack source code is no longer maintained. Moreover, because the focus is placed on CAMs, the newest CPS standards are also not implemented. Other studies focus on only the integration of V2X communication into a specific module in the AD stack, such as the perception [1, 4, 7] or planning [2] pipeline. Although this is sufficient for evaluating the effects of V2X communication on a single module, more information is needed to enable the experimentation and evaluation of the effects of V2X communication on the end-to-end (E2E) AD software as a whole.

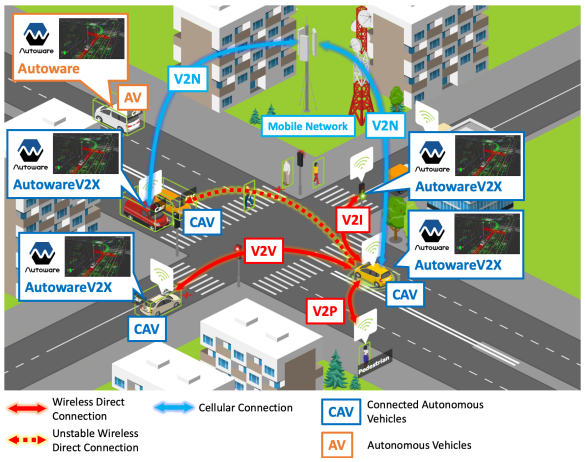


Figure 1: V2X Communication using AutowareV2X

In this study, we propose AutowareV2X, an AD software system that is equipped with a fully functional V2X communication stack. Figure 1 gives an overview of how AutowareV2X can be utilized to realize larger-scale V2X communication schemes.

2 PROPOSED SYSTEM - AUTOWAREV2X

2.1 System Architecture

AutowareV2X is a V2X communication module that can be integrated into the widely used open-source AD software stack, Autoware, to realize CAVs. The system architecture for the implementation is shown in Figure 2. Autoware uses sensing and HD map information in order to execute the entire AD stack from perception, localization, decision, and planning to control. It is based on a ROS2 middleware; thus, all internal messages are shared through a publish-subscribe architecture. AutowareV2X can be integrated into Autoware through an Ethernet interface, and all relevant messages from Autoware can be converted and packed into V2X messages. Because both Autoware and AutowareV2X are loosely decoupled, the two components can be placed on separate hardware to accommodate more use cases.

AINTEC 2022, Dec 19–21, 2022, Hiroshima, Japan
2022. ACM ISBN 978-x-xxxx-xxxx-x/YY/MM…$15.00
https://doi.org/10.1145/nnnnnnn.nnnnnnn

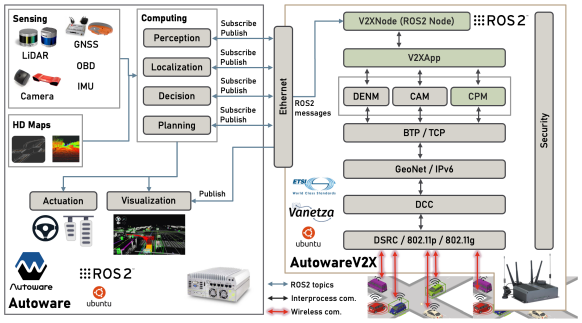


Figure 2: System Design and Architecture

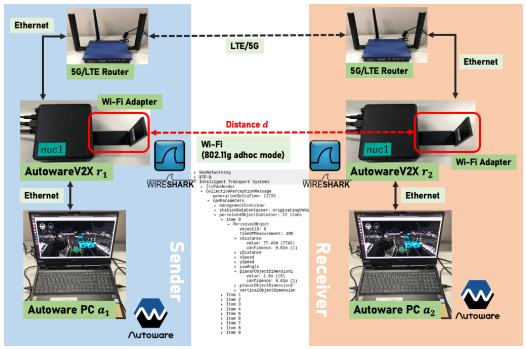
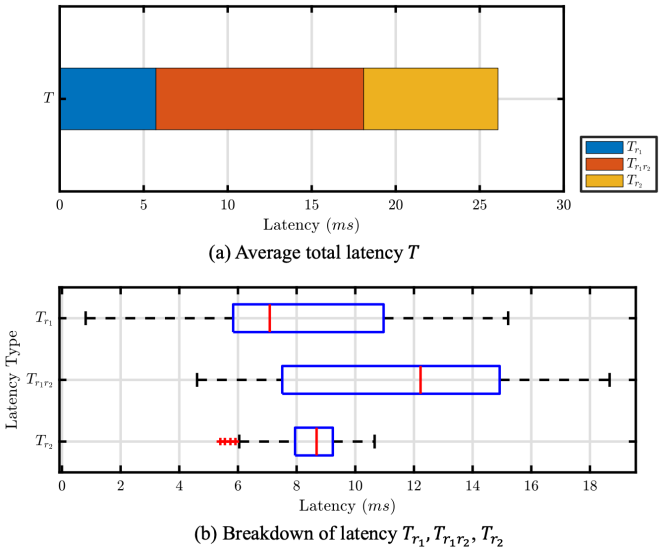


Figure 3: Indoor Experiments Setup



(a) Average total latency T

(b) Breakdown of latency $T_{r_1}, T_{r_1r_2}, T_{r_2}$

Figure 4: Total latency and its breakdown

V2XNode functions as the interface between the V2X communication stack and the ROS2-based Autoware, while *V2XApp* is responsible for common tasks necessary for V2X communication, cross-layer network configuration, and the management of various facilities such as CAM and Collective Perception Message (CPM).

3 EVALUATION

3.1 Experimental Setup

The performance metrics of AutowareV2X were evaluated on actual hardware in the form of indoor experiments. The setup of the indoor experiments is shown in Figure 3. Autoware is run on hosts a_1 and a_2, while the V2X communication router is executed on routers r_1 and r_2. Host a_1 and router r_1 are connected by an Ethernet interface, and these two hosts comprise the AutowareV2X system. Also, host a_2 and router r_2 are set up in the same configuration.

A recording of real-life sensor information in the form of a ROS2 rosbag is fed into Autoware that runs on host a_1. The perception module of Autoware detects nearby objects, and sends the perception information to V2X communication router r_1 over the Ethernet connection. The V2X communication router then converts the information received from Autoware into a CPM, before sending the CPM out of a Wi-Fi interface. Router r_2 then receives the CPM and converts the CPM data into an Autoware-compatible format before forwarding the perception information to Autoware running on host a_2. Routers r_1 and r_2 communicate with each other using the 802.11g ad-hoc mode, and the distance between them, d, is set to 5 m.

3.2 Evaluation Metrics and Results

AutowareV2X was primarily evaluated through the packet delivery ratio (PDR) between the sender and receiver routers, and the E2E latency T, which we define as the time taken for the perception information to reach from a_1 to a_2. Latency T is given by

$$T = T_{r_1} + T_{r_1 r_2} + T_{r_2} \tag{1}$$

where T_{r_1} and T_{r_2} are the execution time at routers r_1 and r_2, respectively, and $T_{r_1 r_2}$ is the communication latency between r_1 and r_2.

The E2E total latency and its breakdown are shown in Figure 4. Perception information can be delivered from the sender AD stack to the receiver AD stack in around 25 ms. The latency breakdown reveals that the communication latency between the two routers $T_{r_1 r_2}$ is about 12 ms, while the execution time at both routers account for less than 10 ms.

4 CONCLUSION AND FUTURE WORK

We proposed AutowareV2X, an autonomous driving software system that is equipped with a fully functional V2X communication stack, providing all the modules within the autonomous driving stack external network connectivity. Experiments showed that AutowareV2X can deliver perception information between stationary ITS-Ss in less than 30 ms.

REFERENCES

[1] H. Masuda et al. 2022. Feature-based Vehicle Identification Framework for Optimization of Collective Perception Messages in Vehicular Networks. , 11 pages.
[2] M. Mizutani et al. 2021. AutoMCM: Maneuver Coordination Service with Abstracted Functions for Autonomous Driving. In *IEEE International Conference on Intelligent Transportation (ITSC) 2021.*
[3] M. Tsukada et al. 2020. AutoC2X: Open-source software to realize V2X cooperative perception among autonomous vehicles. In *The 2020 IEEE 92nd VTC2020-Fall.* Victoria, B.C., Canada.

[4] R. Zhang et al. 2022. Design, Implementation, and Evaluation of a Roadside Cooperative Perception System. *Transp. Res. Rec.* (June 2022), 03611981221092402.
[5] S. Kato et al. 2018. Autoware on Board: Enabling Autonomous Vehicles with Embedded Systems. In *2018 ACM/IEEE 9th International Conference on Cyber-Physical Systems (ICCPS)*. 287–296.
[6] S. Laux et al. 2016. Demo: OpenC2X — An open source experimental and prototyping platform supporting ETSI ITS-G5. In *2016 IEEE Vehicular Networking Conference (VNC)*. 1–2.
[7] T. Wang et al. 2020. V2VNet: Vehicle-to-Vehicle Communication for Joint Perception and Prediction. In *Computer Vision – ECCV 2020*. Springer International Publishing, 605–621.
[8] ETSI. 2017. ITS; Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service; EN 302 637-2 - V1.3.1 .
[9] ETSI. 2019. ITS; Vehicular Communications; Basic Set of Applications; Analysis of the Collective Perception Service (CPS); Release 2; TR 103 562 - V2.1.1 .