Automated and Connected Driving in Urban Scenarios

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***Abstract*—Scenarios for automated driving in inner-city applications differ heavily from highway or rural road scenarios. Various challenges like obstacles in the sensors field of view and actions beyond the vehicles sensory reach can be overcome by using wireless communication. This paper focuses on current developments in Car2X communication standards. Therefore, the various communication protocols and standards are described and their applications are detailed. The described wireless technologies involve basic communication standards like Bluetooth and Wi-Fi, as well as advanced implementations, such as cellular data and the IEEE standard 802.11p WAVE. The approach presented here focuses on the evaluation of these wireless technologies for various vehicle applications in urban scenarios. The advantages, as well as the challenges of the different protocols are determined and their suitability for different use-cases is described and validated. Concluding, the implementations are described exemplary by detailing the developed applications at the Institute of Automotive Engineering, TU Braunschweig.**

Keywords–Car2X communication, 802.11p, WAVE, wireless vehicular systems, automated , cooperative driving

I. Introduction

Automated vehicles, as well as human drivers have to deal with similar issues when it comes to inner-city driving. Sharp corners and obstacles like buildings, plants and city infrastructure limit the automated vehicle's sensory field of view. Furthermore, objects out of the vehicle sensors' reach are not detectable, yielding a potential hazard. Other than the human driver, the vehicle can overcome this issue by connecting to other vehicles and surrounding infrastructure. This connected vehicular systems compensate the potential drawbacks mentioned beforehand by exchanging relevant dates with other traffic participants. Especially the need for cooperative driving, i.e., driving in cooperation with not connected and automated road users, in urban scenarios yields this Car2X communication to adapt to the ever changing scenarios.

Comprised in this communication can be, among others, informations each traffic participant sends about himself, such as speed, planned trajectory and position [1]. Furthermore, the communication partners can send object lists and other information regarding their surroundings.

Equipping automated vehicles with advanced communication units massively increases the adaptability of these vehicles and vehicular networks.

This paper focuses on the communication protocols for connected vehicles as implemented at the Institute of Automotive Engineering (IAE), TU Braunschweig. Therefore, the used communication protocols are described and their usage is detailed. The introduced standards include Bluetooth, WiFi, cellular data and the dedicated IEEE standard for Car2X-communication, 802.11p.

After detailing these protocols and giving a short overview of current exemplary applications at the IAE, the assets and drawbacks of each standard are stated. Concluding, a lookout on potential challenges and future developments is presented.

II. Hardware Base and used Communication Standards

The introduced communication systems are all implemented on two test vehicles at the Institute of Automotive Engineering. The first vehicle is called *Testing and Engioneering of Automated driving SYstems* (TEASY III), the second vehicle *Testing of Integrated Automation and MOnitoring Systems* (TIAMO). Both vehicles are equipped with various sensors and controllers in order to develop automated driving functions. These sensors include mono and stereo cameras, radars and 360° laserscanners for advanced object detection. This sensor and controller setup enables these vehicles to drive automatically in various scenarios, such as highways, rural roads and urban environments.

Especially automated driving in urban environments has a much higher amount of relevant data compared to other driving environments. Since the ego-vehicles sensors have a limited reach and their line of sight can be blocked by various obstacles, vehicles in urban scenarios have to constantly adapt their trajectory planning to the ever changing boundary conditions. This yields the need for connected vehicular systems as described in the following sections.

A. Bluetooth

The IEEE standard 802.15.1 Bluetooth is a dedicated short range wireless communication protocol [2]. Since most modern mobile devices support Bluetooth connections, this standard is very suitable to transfer real time vehicle data quickly and to control various vehicle functions remotely [3]. Since the range of Bluetooth connections is fairly short, the applications at the IAE comprises mainly of quick and modular connections within the vehicle. Among these applications is the linkage between vehicle electronics and the passengers mobile devices, as well as a the communication between the vehicle's central controller and a test manager [4]. This makes it possible to control the vehicles automated driving functions remotely and comfortably from mobile devices.

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Since Bluetooth has been developed as a wireless alternative to RS-232, connections can be set up fairly quick and with only a basic handshake between the participating systems. This makes it highly suitable for short and very sporadic data transmissions between vehicles and mobile devices or other vehicles over very short distances.

B. 802.11 b/g/n WLAN

Another widely spread wireless communication is the IEEE standard 802.11b/g/n for *Wireless Local Area Networking* [5], often abbreviated to *Wi-Fi* or *Wireless Fidelity*. This communication standard combines high data rates with intermediate range. Due to this features, this protocol is highly suitable for transferring large amounts of data between vehicle and infrastructure. Since WLAN requires the participants to register in the network before the beginning of the communication, it takes relatively long until actual payload can be transferred. This network protocol is used at the IAE to update the vehicles' software modules remotely, to transfer measured data and to establish a communication between to vehicles. This enables applications like platooning. Hereby, two cars travelling in the same direction connect via such a local network in order to transfer vehicle data or join their trajectory planning.

C. Cellular Data

Cellular Data (i.e., LTE as state of the art and 5G as a future developmen) enables the test vehicles to communicate over very long distances [6]. Since every vehicle dials into the closest cellular radio cell and changes the cells dynamically when driving, cellular data allows the connected vehicles to establish a stable long-term connection over long distances. A downside of this dynamic changing of cells is that the connection can be disturbed for a short time while driving.
Thus, the test vehicles can connect to distant city-infrastructure via cellular data and communicate less time-critical data. The IAE's vehicles use this communication standard to transmit their positions and planned trajectory to other traffic participants and the involved infrastructure. This enables the test vehicles to adapt their track planning to potentially occurring obstacles or traffic peaks.

D. 802.11p WAVE

The most advanced standard in Car2X communication is the on the IEEE Norm 802.11p based WAVE protocol (**W**ireless **A**ccess in **V**ehicular **E**nvironments) [7]. This version of the WLAN-Norm utilizes a special frequency band at 5.9 GHz and forgoes the process of registering to the network. Every traffic participant broadcasts their messages to all other participants in reach.
In order to enable the messages to reach targets further away, the WAVE protocol uses knot-hopping similar to delay tolerant networks (DTN) [8]. Hereby, messages are configured to be forwarded a defined number of times. The first test vehicle sends a message, which is then received and forwarded by all other participants in reach. These participants can be other test vehicles or infrastructure units. The messages can be divided into two main types for different applications [9]:

- CAM: Cooperative Awareness Message:
  This message contains cyclic status information send by every participant continuously
  Examples: Ego vehicle's position, personal identification, sensory information
- DENM: Decentralized Environmental Notificantion Message:
  This message contains non-cyclic information on special events
  Examples: Position of obstacles or potential hazards, incoming emergency vehicles

This communication concept makes 802.11p WAVE very suitable for dynamic applications, such as connected driving in urban scenarios. Traffic participants can communicate quickly and without the need to conduct a registration to the network. While this speeds up the communication establishment, it also can lead to messages not reaching their destination because of missing links. The absence of such registration process yields the use of other methods for securing the communication, this is specified in the corresponding security norm IEEE 1609.2 [9].
At the IAE, this communication protocol is exclusively used for urban scenarios. The test vehicles exchange their driving intentions with each other quickly. Since this information is broadcasted, the test vehicles can communicate with each other or city infrastructure even when crossing each other or passing by quickly.

III. Conclusion and Lookout

Automated driving in urban scenarios demands for special communication standards. This Car2X communication increases the automated vehicles' performance by extending the on-board sensors with infrastructure information and the sensory data of other traffic participants. By equipping automated vehicles with these communication modules, the adaptability on the ever changing urban driving environment is increased heavily. However, when increasing the amount of connectivity and adaptability it has to be taken care of not to impair the security and safety of such systems.
This paper describes the Car2X communication standards used at the Institute of Automotive Engineering and details on the current applications in the context of urban automated driving. The described variants cover Bluetooth, 802.11b/g/n WLAN, Cellular Data and 802.11p WAVE. These four communication standards are detailed regarding their assets and drawbacks. This comparison yields various applications for which each described variant is variously suitable.
The focus of future work on this promising topic of Car2X communication is the combination of these different network interfaces in order to achieve a higher amount of adaptability by automated connected vehicular systems. Furthermore, it has to be made sure that while adding connectivity and adaptability, security is key to increase these systems safety.
In order to achieve this, the ongoing research described in this paper has to further investigate the potentials of Car2X communication with special regards to security issues. Particularly, 802.11p and its security norm IEEE 1609.2 [9] has to be evaluated further.

References

[1] H. Steubing, M. Bechler, D. Heussner, T. May, I. Radusch, H. Rechner, and P. Vogel, "simtd: a car-to-x system architecture for field operational tests [topics in automotive networking]," IEEE Communications Magazine, vol. 48, no. 5, May 2010, pp. 148–154.

[2] J. C. Haartsen, "The bluetooth radio system," IEEE Personal Communications, vol. 7, no. 1, February 2000, pp. 28–36.

[3] J. r. Lin, T. Talty, and O. K. Tonguz, "On the potential of bluetooth low energy technology for vehicular applications," IEEE Communications Magazine, vol. 53, no. 1, January 2015, pp. 267–275.

[4] H. Znamiec, B. Reuber, R. Henze, and F. Kücükay, "A Method for the Efficient Testing of new Automated Driving Functions," Fast Zero, 2017.

[5] "Ieee standard for information technology–telecommunications and information exchange between systems local and metropolitan area networks–specific requirements - part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications," IEEE Std 802.11-2016 (Revision of IEEE Std 802.11-2012), Dec 2016, pp. 1–3534.

[6] E. Hossain, M. Rasti, H. Tabassum, and A. Abdelnasser, "Evolution toward 5g multi-tier cellular wireless networks: An interference management perspective," IEEE Wireless Communications, vol. 21, no. 3, June 2014, pp. 118–127.

[7] D. Jiang and L. Delgrossi, "Ieee 802.11p: Towards an international standard for wireless access in vehicular environments," in VTC Spring 2008 - IEEE Vehicular Technology Conference, May 2008, pp. 2036–2040.

[8] M. Doering, S. Lahde, J. Morgenroth, and L.Wolf, "IBR-DTN: An Efficient Implementation for Embedded Systems," Chants '08, 2008, pp. 117–120.

[9] T. Schütze, "Automotive Security: Cryptography for Car2X Communication," Rohde + Schwarz, 2011.