Remote Control Architecture for Autonomous Electric Minibuses – Preliminary Study

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Abstract. The paper deals with a remote control architecture dedicated for autonomous electric minibuses. The proposed architecture can be used to control the vehicle in the direct mode or with the use of a semi-autonomous functionality. The main objective of the paper is to study the performance of LTE network in the task of remote control of the vehicle. The preliminary tests were carried out in a relevant environment. The obtained results proved that LTE network can be successfully applied as a standard of wireless broadband communication for remote control of vehicles with a semi-autonomous mode.

Keywords: electric cars, autonomous minibuses, remote control, wireless communication.

1 Introduction

Autonomous buses have become increasingly popular in recent years [1]. These can be seen as the mean to revolutionize transportation and to change the whole paradigm in the near future. The autonomy is divided into five levels by the Society of Automotive Engineers SAE J3016 [2], where Level 0 deals with no autonomy at all, whereas Level 5 corresponds to full autonomy in any conditions. This is no longer a problem to show examples of low-speed autonomous buses operating up to Level 4, see e.g. [3]. However, self-driving in Level 4 is supported only to limited operational design domain [2]. In this mode, the vehicle must be able to safely abort the trip, e.g. slow down and park the car, if the driver does not retake control. When the vehicle cannot return to the self-driving mode, the further acting of the vehicle is not possible without helping of the driver. This is a more difficult issue in a case when there is no driver inside the car. Such scenarios usually need a teleoperation mode which enables the vehicle to be taken over in case human supervision is needed. This paper is focused on communication issues related to the remote control architecture dedicated for autonomous electric minibuses.

2 Remote Control Architecture

The proposed configuration of the hardware components is shown in Fig. 1. The remote control system consists of a remote operator in charge of driving the vehicle; a PC-class computer that acts as a server with a fixed public IP and has indirect access to the LTE network via WAN; steering wheel and control pedals for generating control signals by the remote operator (not shown in the picture); monitors presenting the image from the camera(s) on the vehicle; TELTONIKA RUTX12 router with variable, public and shared IP, access to LTE network and a set of antennas (not shown in the picture); NRU-120S on-board computer for communication via the ROS network and video streaming; PCAN-USB Pro FD analyzer enabling preview and interaction with the CAN 2.0 bus (not shown in the picture).

The components of the remote control system are connected to an internal VPN network. The on-board computer is also connected to the MicroDAQ device, which is the gateway in communication with the other modules on the vehicle (not shown in Fig. 1). The system is currently under development, therefore the research presented in this article was carried out using an NVIDIA Jetson AGX Xavier Development Kit and an LTE mobile phone access point on the vehicle side, instead of the NRU-120S on-board computer and TELTONIKA RUTX12 router.

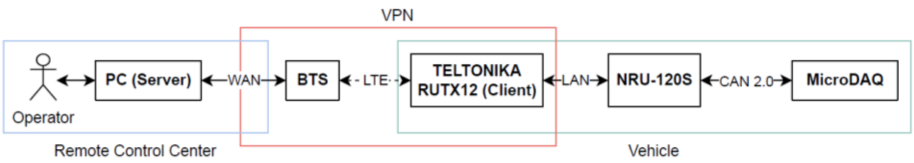

Fig. 1. Proposed Remote Control Architecture

3 Preliminary Results and Discussion

The communication system of the remote-control system was verified in a relevant environment (TRL6). The tests compared data transmission latency and frame loss measured for two LTE providers (a and b) with reference measurements made with Ethernet and wi-fi interfaces. A stationary PC connected to the internet and located at the Faculty of Mechanical Engineering of Silesian University of Technology (Gliwice, Poland) was the sender.

During the verification study two types of data were sent via TCP: (1) a stable video stream from a web camera and (2) ROS-based control frames. Latency was measured by comparing the timestamps embedded in the data frames with current time on the receiver. Image acquisition and display latencies, as well as any possible control input latencies were not considered. The receiver was placed in Świętochłowice (SW), in Czechowice (CZ) and then in Wielowieś (WW) in Poland. Receiver and sender were synchronized to a custom NTP server running on the sender PC.

Video was streamed from a web camera connected to the PC. The stream was encoded using OpenCV and JPEG with 90% quality. Image resolution was 1280x720 pixels at 30 FPS. Table 1 summarizes chosen results. Q1-3 represent the first, the second and the third quartile. Video was streamed outside of ROS network.

Table 1. Video streaming results for different interfaces

#	Interface	Receiver Location	Latency [ms]							Frames lost
			Min	Max	Avg	StDev	Q1	Q2	Q3	
1	Ethernet	SW	17.7	298.3	22.9	28.3	18.2	19.1	19.6	0.0%
2	Wi-fi	SW	24.6	1767.2	166.2	31.2	34.2	89.9	362.0	0.0%
3	LTE (a)	SW	28.2	698.1	70.0	101.2	36.7	41.5	50.6	0.0%
4	LTE (b)	SW	22.1	1761.5	352.0	412.4	36.7	121.2	652.2	0.0%
5	LTE (a)	CZ	29.8	449.3	44.9	44.1	33.9	38.5	41.9	0.0%
6	LTE (b)	CZ	35.9	756.2	61.9	100.2	38.9	43.1	46.1	0.0%
7	LTE (a)	WW	18.7	431.9	34.4	21.7	25.0	29.5	49.4	0.0%
8	LTE (b)	WW	1.5	1312.7	97.6	277.8	3.6	5.8	12.1	0.0%

Control signals were simulated using timestamped ROS messages of types Empty, Bool, Int, UInt, Float and String. They were sent concurrently on different topics at 1 Hz rate. The measured latency was the difference between receive time and the timestamp embedded in the message. Chosen results are presented in Table 2.

Table 2. Control frames received using different interfaces

#	Interface	Receiver Location	Latency [ms]			Frames lost
			Min	Max	Avg	
1	Ethernet	SW	22.3	18.3	20.5	0.0%
2	Wi-fi	SW	18.4	832.4	155.0	0.0%
3	LTE (a)	SW	20.2	150.0	66.6	0.0%
4	LTE (b)	SW	15.7	256.9	142.9	0.0%
5	LTE (a)	CZ	0.5	279.6	144.9	0.0%
6	LTE (b)	CZ	35.9	756.2	61.9	0.0%
7	LTE (a)	WW	9.0	218.3	144.8	0.0%
8	LTE (b)	WW	12.1	140.8	81.8	0.0%

Additionally, another experiment was conducted by measuring video latency while driving from Czechowice to Gliwice with the receiver onboard. The vehicle was moving approximately at speed of 30 – 40 km/s. Only LTE (provider b) was used.

Less dense areas far from city centers featured significant reduction in latency due to clear path to BTSs and less noise, while Świętochłowice provided the largest latency. The performance measured for both LTE providers differs much between the sites. Dynamic test also highlighted bottlenecks in areas with no BTS coverage, such as forests. Nevertheless, about 70% of the video frames were received within 70 ms.

4 Conclusion

This paper shows some partial results of the study concerned with communication performance of the proposed remote control architecture. The main objective was to explore the applicability of LTE network for remote control of the vehicle. The approach was verified in a relevant environment (TRL6). It was initially proved that LTE network can be successfully applied as a standard of wireless broadband communication for remote control of vehicles equipped with a semi-autonomous driving mode. Moreover, some limitations have to be taken into account (i.e. areas with no BTS coverage, such as forests, or even zones where a change between BTSs is required) to create the final solution dedicated for real world conditions (TRL9). The more detailed analysis is needed taking into account existing solutions i.e. provided by Freedom Robotics [4] or DriveU [5] in order to identify pros and limitations of the proposed architecture.

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