Testing MPT-GRE Multipath Solution in Vehicular Network V2I Communication

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***Abstract*—A vehicular network is a communication system comprising of vehicles equipped with radio-interfaces, where the endpoints are capable of exchanging data and communication between each other (Vehicle-to-Vehicle, V2V), as well as with another mobile network or fixed infrastructure (Vehicle-to-Infrastructure, V2I). The numerous applications used in vehicles typically require seamless and increasingly fast and reliable network connections, which poses a challenge for the wireless network technologies at our disposal today. MPT-GRE, developed at the University of Debrecen, is a multi-interface access technology, which could offer a novel solution to satisfy the requirements of the services used in vehicular networking applications. Given that MPT-GRE enables the simultaneous usage of multiple network interfaces and IP-routes for vehicles, it promises to be an effective solution for vehicular networks. In this paper, we are examining the efficiency of MPT-GRE using a self-driving car model in a dual-interface Wi-Fi environment.**

***Index Terms*—MPT-GRE, multipath communication, redundancy, vehicular network (VANET), Vehicle-to-Infrastructure (V2I) communication, throughput**

I. Introduction

The vehicular ad-hoc network, which is a special subtype of MANETs, is among the currently relevant research fields. Nothing proves this more than the number of publications and projects released in this topic during the past decade (see e.g. [1]–[4]). The vehicular network is one of the key components of intelligent transportation systems (ITS). In such a system, vehicles can communicate with each other, and the roadside infrastructure as well (see Figure 1)).

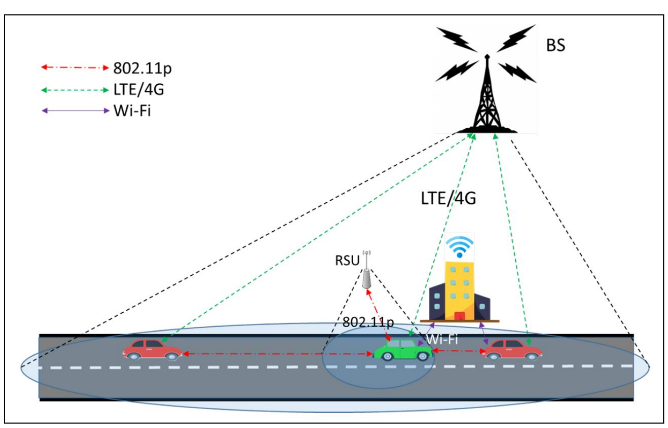

Fig. 1. A typical VANET communication environment [5]

The constant mobility of the vehicles poses a challenge for establishing and maintaining a stable and robust connection between endpoints. At the same time, most vehicle applications have strict requirements when it comes to delay, jitter, data loss rates and reliability. There are some efforts aimed at improving the communication performance of vehicular networks while using multipath communication channels (see e.g. [6]–[12]). Nowadays, vehicles can be equipped with different types of communication interfaces (e.g., Wi-Fi, 802.11p, LTE, 4G, 5G). Numerous wireless communication technologies exist, but IEEE 802.11p is considered the default standard for inter-vehicle communication solutions [13]. MPT-GRE[1] could be a promising approach for improving the robustness and throughput efficiency for vehicular network connections. Compared to traditional single-path communication, MPT-GRE could benefit the mobility and increase redundancy along with throughput rates.

In effect, MPT-GRE, developed at the Faculty of Informatics, University of Debrecen, is the multipath version of the GRE encapsulation protocol defined in RFC8086[2]. Its operating principle is substantially different to that of the

[1]The MPT-GRE Project official website: https://irh.inf.unideb.hu/˜szilagyi/index.php/en/mpt/

[23]GRE-in-UDP Encapsulation standard: https://tools.ietf.org/html/rfc8086

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+-----------------------------------------------+
|             Application (Tunnel)              |
+-----------------------------------------------+
|               TCP/UDP (Tunnel)                |
+-----------------------------------------------+
|              IPv4/IPv6 (Tunnel)               |
+-----------------------------------------------+
|                  GRE-in-UDP                   |    +-----+
+-----------------------+-----------------------+<--| MPT |
|    UDP (Physical)     |    UDP (Physical)     |    +-----+
+-----------------------+-----------------------+
| IPv4/IPv6 (Physical)  | IPv4/IPv6 (Physical)  |
+-----------------------+-----------------------+
|    Network Access     |    Network Access     |
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Fig. 2. MPT-GRE layered architecture

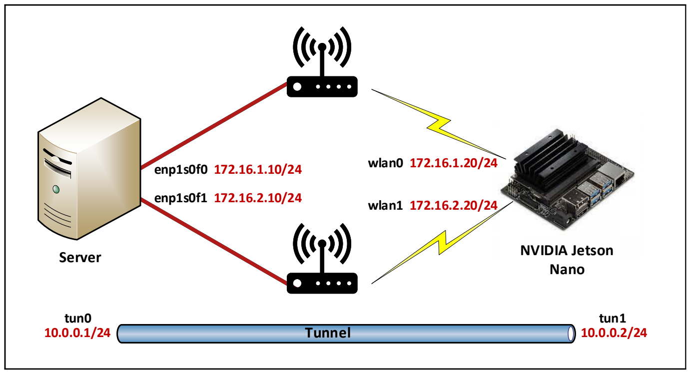

Fig. 3. Test environment

traditional TCP/IP and the MultipathTCP architectures as well. MPT-GRE utilizes a new tunnel layer and port, which enables the simultaneous use of multiple physical interfaces within a given communication. Specific adaptation of applications developed for single-interface use is not necessary as these remain operational in the multipath environment as well, since the Application layer in the new architecture also sees a single interface, with the difference being that it is not a physical, but a logical tunnel interface. Below this interface, it is MPT-GRE that takes care of mapping and distributing the traffic to the physical interfaces. Thanks to the MPT-GRE architecture, a standard GRE tunnel-connection is established between the endpoints for the entire duration of the communication. Working with MPT-GRE, data transfer is feasible using IPv4/IPv6, as well as over UDP/TCP (see Figure 2)).

Assessing the efficiency of MPT-GRE has now been the topic of numerous previous publications (see [14]–[17]). In this paper, we are examining the aggregation capability of Wi-Fi interfaces during V2I communication in a dual-path MPT-GRE environment.

II. Test environment

We used the environment described below to perform our measurements (see Figure 3)).

Fig. 4. Image of University of Debrecen Autonomous Vehicle - "DAVE" [18]

We emulated roadside infrastructure using a PC running the Linux Ubuntu 20.04 LTS operating system. On the client-side, we used an NVIDIA Jetson Nano card, as this was the development card integrated on our self-driving car-prototype as well (see Figure 4)). We installed the same Linux Ubuntu version that the applications running on our prototype were using as well, namely version 18.04 LTS.

To create the two independent paths for the double-path test environment, we connected two Netgear AC Wi-Fi routers to the two Gigabit Ethernet ports on the PC, while equipping our NVIDIA card with two Wi-Fi network adapters. The exact device parameters were the following:

- PC:
  - Gigabyte Z77-D3H motherboard with Intel Z77 chipset
  - 8 threads (4 physical cores) on an Intel Core i7-3770K 3.50GHz processor
  - 4x4GB 1600MHz DDR3 SDRAM
  - Intel PT Dual 1000 Gigabit Ethernet server interface
  - Ubuntu Server 20.04.3 LTS 64-bit operating system with 5.4.0-89-generic Linux kernel module
- Netgear R7000 – Nighthawk AC1900 Smart WiFi Router
- Netgear R7100LG – Nighthawk 4G LTE Modem Router
- NVIDIA Jetson Nano Developer Kit[3]
  - Architecture: arm64
  - Ubuntu 18.04.6 LTS 64-bit operating system with 4.9.253-tegra Linux kernel module
- Realtek USB3.0 802.11ac Dual Band 1200M WiFi adapter
- Intel Wireless 8265/8275 Dual Band Wireless-AC 8265 Wi-Fi adapter

On both the PC and the NVIDIA card, we downloaded the latest version of MPT-GRE from GitHub[4], then proceeded to compile and install it as per the provided user manual. We have successfully established the tunnel connection between the two endpoints in a relatively short time, the actual challenge was more-so the fine-tuning of the system parameters.

[3]https://developer.NVIDIA.com/embedded/jetson-nano-developer-kit
[4]https://github.com/unideb-net/mpt-gre

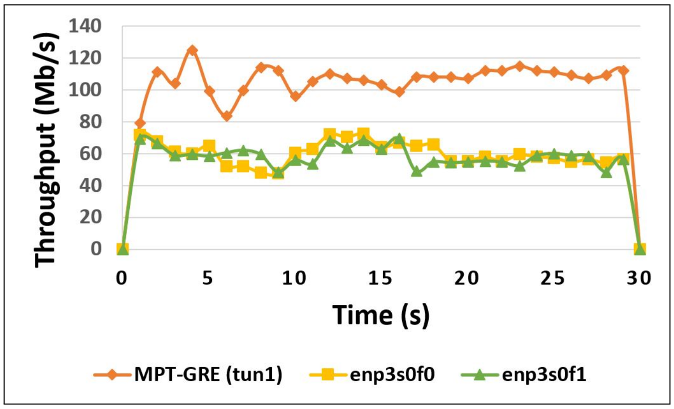

Fig. 5. *iperf3*-based data throughput measurement in our dual-path 2.4 GHz Wi-Fi environment

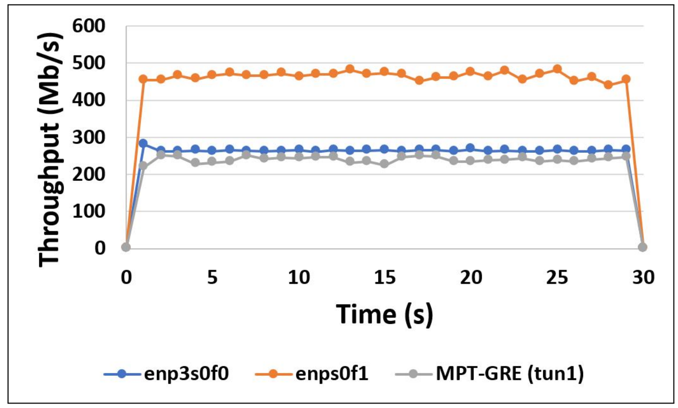

Fig. 7. *iperf3*-based data throughput measurement in our dual-path 5 GHz Wi-Fi environment

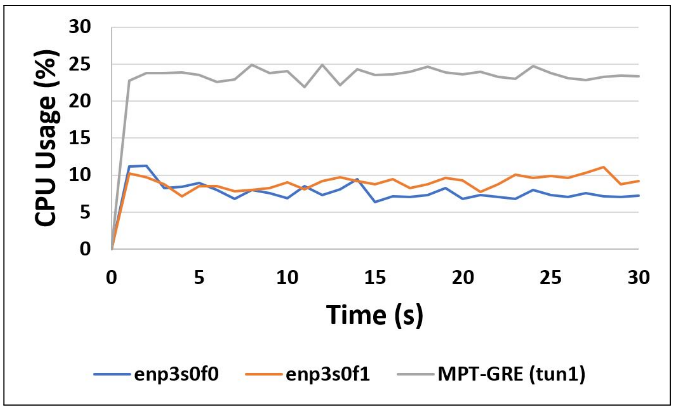

Fig. 6. CPU utilization during *iperf3* measurement in our dual-path 2.4 GHz Wi-Fi environment

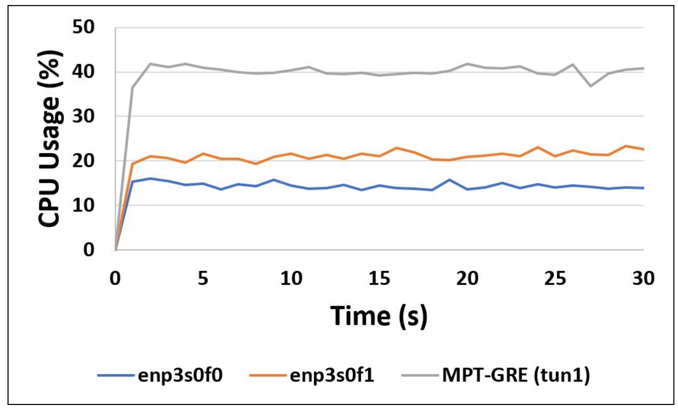

Fig. 8. CPU utilization during *iperf3* measurement in our dual-path 5 GHz Wi-Fi environment

III. Test results

We performed multiple series of measurements for examining the efficiency of MPT-GRE: *iperf3*-based tests in 2.4 GHz and 5 GHz Wi-Fi environments, CPU utilization-based measurements in 2.4 GHz and 5 GHz Wi-Fi environments, and redundancy tests in communication over MPT-GRE. We repeated every measurement type ten times, and the default duration of the tests was 30 seconds. We used Python scripts to automate the series of measurements. The deviation between the test results was minimal, under 3% in all cases.

First, we started with a baseline reference measurement in a single-path environment. In this case, we measured the data throughput between the physical interfaces without the use of MPT-GRE. Measurements with *iperf3* for both of the Wi-Fi connections came in at around 60 Mb/s. Once MPT-GRE was enabled, we started measuring the aggregated throughput between the tunnel interfaces of the two endpoints. With an optimal positioning setup of the Wi-Fi antennas, we measured a rate of 107 Mb/s on average (see Figure 5)).

At the same time, we were also measuring CPU utilization for all three interfaces (enp3s0f0, enp3s0f1, tun1) with the help of the *sar* program. During single-path data transfer the average load on the CPU was under 10%, while the usage of MPT-GRE increased this to around 23% (see Figure 6)).

Since the Wi-Fi routers used for our measurements supported communication over 5 GHz, we performed our previous tests in a 5 GHz environment as well. In this setup, the performance of MPT-GRE drastically decreased, not even equaling that of the single-path environment. The data throughput rate between the physical interfaces proved to be asymmetrical. The rate measured on the first path was 246 Mb/s on average, while on the second path this increased to 469 Mb/s. In line with previous research findings (see e.g. [19]), MPT-GRE could not efficiently handle the asymmetrical multipath environment. Thus, the aggregated performance it provided hovered around 247 Mb/s (see Figure 7)).

We repeated the CPU load measurements as well in the 5 GHz environment (see Figure 8)). The baseline CPU load measurement for the first path showed around 13%, while on the other path we measured about 20%. In case of data transfer over MPT-GRE, the load value increased to 40%.

In our last measurement series, we examined the capability of MPT-GRE for redundant communication in a 2.4 GHz Wi-Fi environment, using *iperf3*. We increased the test duration to 100 seconds here. We started the measurement in the dual-

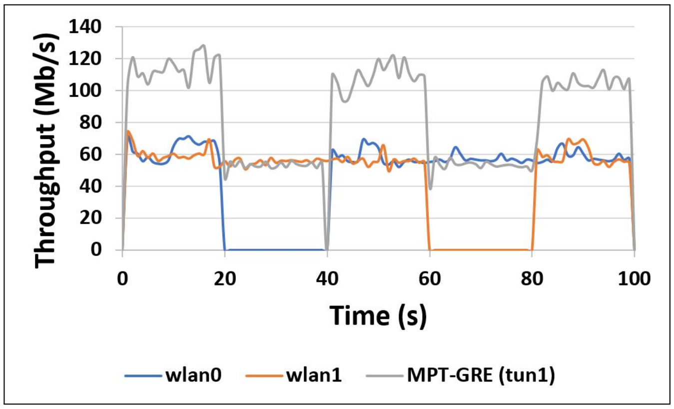

Fig. 9. MPT-GRE redundancy measurement

path environment, then disabled interface enp3s0f0 after 20 seconds. We enabled it again at 40 seconds, then disabled interface enp3s0f1 at the 1-minute mark. After 20 more seconds have passed, we enabled this one again too, then resumed the measurement for yet another 20 seconds. The redundancy capabilities of MPT-GRE are shown on Figure 9).

IV. Conclusions

In this paper we examined the efficiency of the MPT-GRE multipath communication solution in a dual-path, Wi-Fi-based, emulated V2I environment. We performed three types of measurement series: *iperf3*-, CPU utilization- and redundancy-based measurements in both 2.4 GHz and 5 GHz environments. Based on our test results, we can draw the conclusion that the MPT-GRE multipath solution is capable of efficiently aggregating the performance of the two Wi-Fi interfaces of the vehicles in a 2.4 GHz environment, if the aggregated speed is around 100 Mb/s and the paths are symmetrical. In the 5 GHz environment, MPT-GRE was not capable of efficient path throughput aggregation. Regarding the CPU utilization, the 2.4 GHz environment showed acceptable numbers, while the 5 GHz environment produced numbers slightly on the higher side. For achieving redundant paths, MPT-GRE can be an excellent solution for vehicular networks. It is capable of dynamically handling interface usage and forwarding data traffic in a redundant way.

Our future plans include further development of MPT-GRE, performing tests in mixed environments (Wi-Fi – LTE/4G), carrying out 802.1p-based measurements, and utilizing a more efficient TCP congestion-control algorithm.

Acknowledgment

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