

CHARISMA – 5G Low Latency Technologies and their Interaction with Automotion ¹Control Loops

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Abstract—This paper presents the low latency improvements achieved by the key technologies in the 5G-PPP CHARISMA project. CHARISMA uses an hierarchically organizes RAN architecture in combination with FPGA based hardware accelerated network functions to achieve the 5G low latency KPI's. We show a significant improvement in the operational results as compared to the initial CHARISMA performance. We also include a visualisation platform showing the latency impact on a discrete automotive control application.

Index Terms—SDN, automotion, hardware acceleration, low latency

I. INTRODUCTION

The Converged Heterogeneous Advanced 5G Cloud-RAN Architecture for Intelligent and Secure Media Access (CHARISMA) project [1] focuses on providing a low latency (LL), secure, and open access Cloud RAN (C-RAN) architecture for 5G networks. In reference [2] use cases have been defined to match the 5G Public Private Partnership (PPP) requirements as defined by the associated Key Performance Indicators (KPIs). Low latency is one of the particularly important 5G topics, since it is expected to have a high impact on future services like Internet of Things (IoT) or tactile applications. [3]–[5] The work described in this paper therefore focuses on the achieved improvements regarding the low latency technologies as developed within CHARISMA and highlights their impact on a discrete automotive control example. Nowadays there are various Discrete Automatic Motion (Automotion) control applications in which devices with actuators and sensors, but without their own on-board decision logic, are controlled by a remote-control-logic. Examples can be found in industrial automation, autonomous vehicles, augmented or virtual reality setups for remote control work and healthcare. [6], [7] Usually, such devices only

have the ability to collect measurement data and forward it to the remote-control-logic. Which then decides upon which actions to take, respectively, in order to achieve the required consequent motion. As such, the device receives the instructions from the remote-control-logic and and subsequently executes them. For such applications, it is therefore very important to achieve the lowest possible latency for the transmission line, in-between the decision logic and the actual execution. [8] According to [4], [6], an end-to-end-latency of a maximum 1 ms and a jitter below 1 μ s need to be achieved.

II. STATE OF THE ART

One of CHARISMA's targets is the improvement of the networks latency to establish the requirements for latency depended application like real-time communication or tactile systems. Therefore two types of network latency are considered end-to-end latency and startup-latency. Startup-latency occurs in the initial phase of network services. e.g the time difference from requesting an video file until the first video packet arrives via the network is considered as start-up latency. The second class: end-to-end-latency is a more crucial factor for the networks latency experience. The end-to-end latency affects every transmitted packet and has so a more high impact on the overall communication performance.

In references [1], [9] several low latency technologies are mentioned:

- A distributed video-caching solution
- Hardware accelerated server Network Interface Cards (NICs)
- Hardware accelerated routing devices, named TrustNode
- An Orthogonal frequency division multiple access Passive Optical Network (OFDM-PON) solution

Except for the distributed caching solution, the proposed technologies use hardware-based packet-forwarding technologies, which speed-up the network traffic in comparison with software-based forwarding. However, the flexibility known from Software Defined

Manuscript received March 20, 2018; revised October 21, 2018.

This work was supported by funding from the EU's H2020 programme under grant agreement No. 671704.

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doi:10.12720/jcm.13.11.667-672

Networks (SDNs) is maintained by providing SDN to hardware mapping mechanisms. In [9], [10] propagation latency's from 2.5 μ s to 10 μ s are measured for the single devices. In comparison the single device latency without hardware acceleration functions was from 165 μ s to 200 μ s.

CHARISMA's targets the transmission in the RAN domain. Therefore a hierarchically network architecture is considered. As considered in [13] this hierarchically structure simplifies the network topology and supports so the latency improvement. The implementation in [18] show that using an treelike network structure enables the network devices to route packets in one clock cycle if the destination network address is available in the devices processing structure.

III. IMPLEMENTATION

The following section gives a more detailed view on the hardware components used, with a summary description of the whole demo setup.

A. Accelerated NIC

The smart NIC, as shown in Fig. 1, [11] is an network interface card for server applications which support SDN rule offloading. If configured, packets are processed and forwarded right inside the network interface card, without any CPU-load. This reduces latency and power consumption. The device uses an artix7 FPGA to offload common firewall and filter functions from the software subsystem into the network card. This enables the server to move these functionalities from the Customer Premise Equipment (CPE) side to the cloud where it can handled faster and more energy efficient as on the CPE side. [17]



Fig. 1. Smart NIC card [17]

B. TrustNode Accelerated Router



Fig. 2. TrustNode – hardware accelerated router

As mentioned in [9], [10], [12] the TrustNode (see Fig. 2) is an research platform for Field Programmable Gate

Array (FPGA)-based packet forwarding. An integrated CPU enables SDN controlled hardware acceleration to process the network traffic. For hierarchical structured networks a special IPv6 packet forwarding schema can be used to speed-up the address lookup in the device itself. [13]

C. OFDM-PON

As shown in [1], [14], [15] CHARISMA includes an 100G Orthogonal frequency division multiple access Passive Optical Network solution. This transmission technology consists of an Optical Line Terminal (OLT) and several optical network units (ONUs). The ONU receives a down-sampled part of the spectrum transmitted from the OLT which enables an easier and more cost efficient implementation of the ONU.

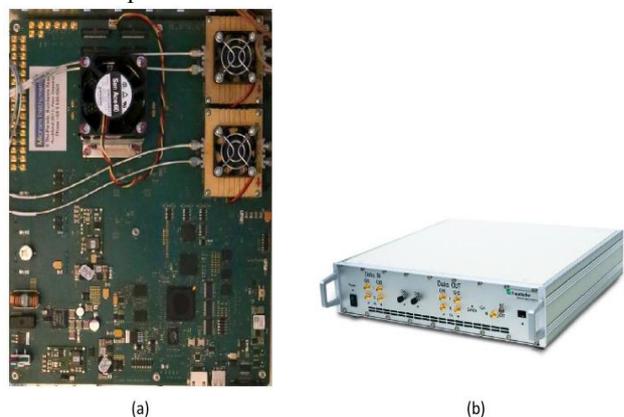


Fig. 3. FPGA platform for OFDM-PON: OLT(a), ONU(b) [17]

D. Automation Sensor/Actor Platform

The automation actor/sensor platform is represented by a Raspberry-Pi (RPI)-based robot with two chain drives and an ultrasonic sensor for collision detection. Fig. 3 shows the main components of the platform consisting of the mobile device itself and a WiFi accesspoint. The measurement data obtained by the sensor are periodically transmitted to the automation controller through an IPv6 TCP stream socket. The same socket is used for the transmission of the control commands from the controller to the actor/sensor platform. The software is written in near-hardware programming languages and optimized for low latency reaction, to achieve a small latency offset. The controller receives the measurement data and decides by a simple threshold implementation if the mobile platform is going to collide with an object spotted by the ultrasonic sensors. If the threshold is triggered a stop command is transmitted to the robot. This involves the network delay, to transmit the measurement data and control commands, two times in the control loop.

The message flow is shown in Fig. 4. The hard real-time condition is that the mobile platform should stop before it collides with the object, the network delay will influence the distance between the robot and the collision object. So the network delay becomes obvious visible and can be measured by an ruler in cm. To adjust the robot behaviour to the conditions of the test network a variable

packet-loop was implemented. This adds a additional field to the control packages. Controller and robot replaying the packages until the incremented field reaches zero. So the robot can be adjusted to the network conditions to visualize several delay magnitudes. The control software can be found in [16].

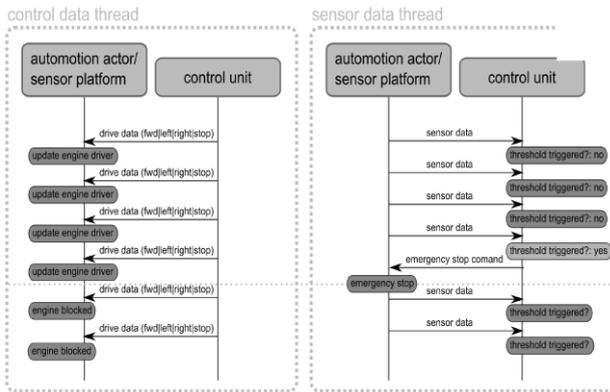


Fig. 4. Automation actor/sensor platform message flow

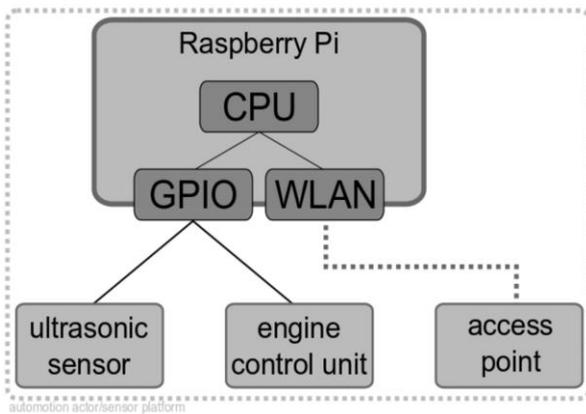


Fig. 5. Automation actor/sensor platform

E. Demo setup

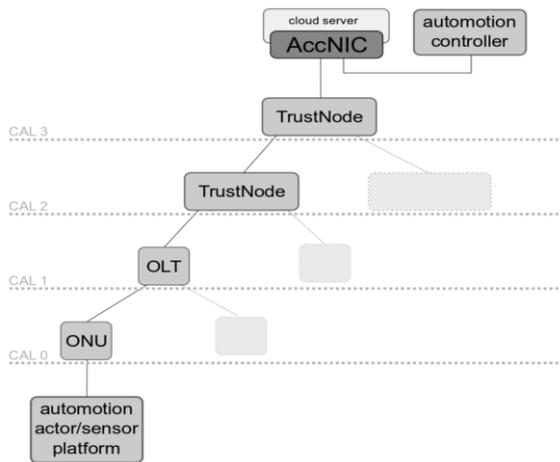


Fig. 6. Demo set-up showing all used components and their integration in the CHARISMA CALs.

Fig. 6 shows the interaction of the CHARISMA low latency components and their integration in the

Converged Aggregation Levels (CALs). [1] The access point of the autonomic sensor/actor platform is connected to the lowest CAL. The robot automation controller is connected to one of the ports of the cloud server. The node devices, ONU, OLT, and TrustNode, provide a hierarchically structured network with low latency characteristics, between the two Endpoints.

The network provides an logical connection between the automation sensor platform and their controller. The network traffic passes all devices between CAL0 and CAL3. Where in the TrustNode routing platform and the Smart NIC device the hardware offloading functions are enabled to provide fast hierarchical IPv6 routing. The smart NIC is configured to simulate a common firewall and Network Address Translation (NAT) functionality.

IV. MEASUREMENT RESULTS

Table I shows the propagation delay measurements of the low latency devices itself. The measurements are achieved by IXIA network analyser and by direct oscilloscope probe measurements on the Physical Layer Chips (PHYs) of the TrustNode.

TABLE I: SINGLE DEVICE DELAYS

Device	Propagation delay
TrustNode	1.95 μ s
acc NIC	10.40 μ s
OFDM-PON	10.00 μ s

TABLE II: E2E DELAY FOR DIFFERENT NUMBER OF NETWORK NODES

node count	E2E-delay	reference delay from [9]	wall distance according to E2E-delay
0	20.40 μ s	200 μ s	2.13 cm
5	30.15 μ s	1025 μ s	1.90 cm
10	39.90 μ s	1850 μ s	1.83 cm
15	49.65 μ s	2675 μ s	1.74 cm
20	59.40 μ s	3500 μ s	1.20 cm

Table II shows the end-to-end-delay measurement values achieved with the network structure shown in Fig. 6.

The measured distance values are statistical sanitised to lower the impact of the mechanical components and the ultrasonic distance sensor reaction time. Fig. 6 shows only one node device per aggregation level we extrapolated the end-to-end delay for a usual amount of hops by simulating the single device delays from Table I by an additional TrustNode mainboard.

Table II and Fig. 7 shows also the impact of the growing network delay to the cloud controlled sensor/actor platform.

The convergence of the network delay to the threshold of the hard real-time condition is shown in the reduced distance between the robot and the collision object. Table II shows the delay for several hop-counts from zero (just including smartNIC and OFDM-PON) to 20 hops.

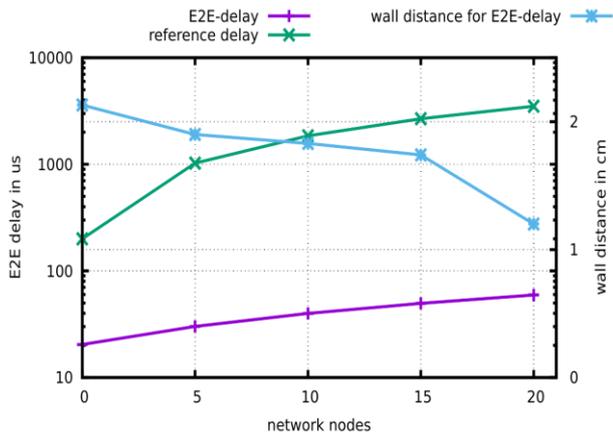


Fig. 7. Plot of measured propagation delay values for different network node counts in comparison to the reference delay from [9].



Fig. 8. Robot sensor, actor platform

The message-loop between controller and robot, which is shown in Fig. 8, was adjusted to allow the robot to safely stop as close as possible in front of an obstacle if the network has the maximum delay of $59.40 \mu\text{s}$.

V. CONCLUSION

End-to-end latency is an essential parameter of future autonomous network control loops, especially in the context of next-generation 5G networking and automation control. In this work we have presented the results of the CHARISMA low latency network devices, including the Orthogonal frequency division multiple access Passive Optical Network, accelerated NIC and TrustNode, to show the impact of the low latency achievement for several network distances in comparison to the reference measurement of the initial CHARISMA network structure. [9] The implemented autonomous control platform example has also been described as a means to visualise the impact of this work. According to Table II the common network distance of 20 hops can be conquered by introducing only $60 \mu\text{s}$ of propagation delay at each node, in contrast to common-place

software-based implementations, where forwarding elements often break the critical threshold of 1 ms several times over.

ACKNOWLEDGMENT

This project has received funding from the EU's H2020 programme under grant agreement No. 671704.

REFERENCES

- [1] M. C. Parker, G. Koczian, F. Adeyemi-Ejeye, *et al.*, "Charisma: Converged heterogeneous advanced 5g cloud-ran architecture for intelligent and secure media access," in *Proc. European Conference on Networks and Communications*, 2016, pp. 240–244.
- [2] M. S. Siddiqui, A. Legarrea, E. Escalona, *et al.*, "Hierarchical, virtualised and distributed intelligence 5g architecture for low-latency and secure applications," *Transactions on Emerging Telecommunications Technologies*, vol. 27, no. 9, pp. 1233–1241, 2016.
- [3] M. Maier, M. Chowdhury, B. P. Rimal, *et al.*, "The tactile internet: Vision, recent progress, and open challenges," *IEEE Communications Magazine*, vol. 54, no. 5, 2016.
- [4] General 5g requirements TS 22.261, 3GPP, 2017. [Online]. Available: http://www.3gpp.org/ftp//Specs/archive/22_seris/22.261/22261-g00.zip
- [5] A. Gupta and R. K. Jha, "A survey of 5g network: Architecture and emerging technologies," *IEEE Access*, vol. 3, pp. 1206–1232, 2015.
- [6] M. Simsek, A. Aijaz, M. Dohler, *et al.*, "5g-enabled tactile internet," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 3, 2016.
- [7] P. Popovski, G. Mange, A. Roos, *et al.*, "Deliverable d6. 3 intermediate system evaluation results," *Ict-317669-metis/d6*, vol. 3, 2014.
- [8] I. Stojmenovic, "Machine-to-machine communications with in-network data aggregation, processing, and actuation for large-scale cyber-physical systems," *IEEE Internet of Things Journal*, vol. 1, no. 2, pp. 122–128, 2014.
- [9] M. Parker, G. Koczian, S. D. Walker, *et al.*, "Ultra-low latency 5g charisma architecture for secure intelligent transportation verticals," in *Proc. 19th International Conference on Transparent Optical Networks*, 2017.
- [10] C. Liß, M. Ulbricht, U. F. Zia, *et al.*, "Architecture of a synchronized Low-Latency network node targeted to research and education," in *Proc. IEEE 18th International Conference on High Performance Switching and Routing*, Campinas, Brazil, Jun. 2017.
- [11] Ethernity Networks, Ace nic - nfv software acceleration nic. (2016). [Online]. Available: <http://www.ethernitynet.com/products/ace-nic/>
- [12] CHARISMA Consortium. CHARISMA D1.3 – hierarchical routing node analysis. Charisma5g.eu. (2017). [Online]. Available: http://www.charisma5g.eu/wp-content/uploads/2015/08/Charisma_D1.3.pdf
- [13] M. Ulbricht and J. Wagner, "Accelerated processing delay optimization in hierarchical networks using lowcost hardware," in *Proc. 10th International Symposium on*

Communication Systems, Networks and Digital Signal Processing, Prague, Czech Republic, Jul. 2016.

- [14] K. Habel, M. Koepp, S. Weide, *et al.*, “100g ofdm-pon for converged 5g networks: From concept to realtime prototype,” in *Optical Fiber Communication Conference, Optical Society of America*, 2017.
- [15] M. Koepp, K. Habel, and V. Jungnickel, “Self-interference-tolerant frequency offset estimation technique for im/dd-based ofdma pon systems,” in *Proc. Photonic Networks, ITG-Symposium*, 2017, pp. 1–7.
- [16] P. Dockhorn and M. Ulbricht. Github Robopi. [Online]. Available: <https://github.com/dog42/robopi>
- [17] CHARISMA Consortium. CHARISMA D2.1 – Inital Architecture Design and Interfaces. Charisma5g.eu. (2017). [Online]. Available: <http://www.charisma5g.eu/wp-content/uploads/2015/08/CHARISMA-D2.1-v1.0.pdf>
- [18] M. Ulbricht, P. Dockhorn, C. Liss and J. Wagner, “Highspeed hierarchical routing – a practical approach to single-clock routing,” in *Proc. 11th International Symposium on Communication Systems, Networks & Digital Signal Processing*, Budapest, Hungary, 2018, pp. 1-6.



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Kai Habel (male) received the Diploma in Electrical Engineering, at Technical University Berlin in 2001. Afterwards he joined the Fraunhofer HHI, in Berlin, Germany, as a Research Assistant, where he works on optical metro, access and in-house networks as well as optical wireless systems. His expertise ranges from physical layer transmission technology to media access and higher layer protocols. During more than 15 years, he was involved in numerous industry driven projects as well as in national and international R&D projects, where he has authored and co-authored numerous scientific publications.



Mike Parke has over 25 years experience in photonics and wireless technologies. He was Technical Manager of the EU H2020 5G-PPP (phase 1) CHARISMA project representing Essex University, and is now currently working in the 5G-PPP (phase 2) METRO-HAUL project. Prior to Essex University, Dr Parker worked for over 10 years at

Fujitsu (1997-2007), located in the UK, USA, and Japan. During his career, he has pioneered many important technologies, including his doctoral research (at Cambridge University, 1993-1996) where he invented the use of liquid crystal on silicon (LCoS) technologies for high-resolution WDM grooming, holographic tunability, and flexgrid wavelength control. While with Fujitsu he invented the use of cascaded and cyclic arrayed-waveguide gratings (AWGs) in a WDM-PON access network topology, now forming the dominant architecture for next-generation PON access networks. In 1998 he invented the application of aperiodic grating structures to photonic crystals, creating the only means to achieve a multi-wavelength photonic bandgap, forming the basis for the world's first electronically-tunable terahertz

quantum cascade laser (QCL). In recent years, he has also pioneered the application of thermodynamic principles to computation and communications theory, inventing the first absolute energy efficiency metric (dBe) for ICT technologies. He has also invented novel microstructured optical fibre using Fresnel zones, azimuthally graded-index (GRIN) fibre, and pioneered the use of optical orbital angular moment (OAM) light for cryptographic telecommunications. He has also innovated in the application of entropy theory to the design of flexgrid elastic optical networking. He left Fujitsu in 2007 and is now Research Fellow at Essex (where he was Fujitsu Visiting Professor from 2003-2007). Dr. Parker has filed over 20 patents and published 172 conference & journal papers over his career.