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Chorus Mobility
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Abstract.

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1 Introduction

This whitepaper addresses the detected gap by introducing the Chorus Mobility solution, thereby answering the question of how to implement a blockchain-based transaction layer that enables a V2X platform for goods and services? In order to answer this question with a separation of concerns, we pose the following subquestions: What is the long term vision of Chorus Mobility? What are the critical requirements and the corresponding architecture of the Chorus V2X platform? What are the system-engagement processes for the stakeholders?

The remainder of this paper is structured as follows: Section 2 introduces supplementary literature and related work. Section 3 outlines the vision of Chorus Mobility. Afterwards, Section 4 analyses the requirements of the system and outlines the resulting system architecture that we derive from the requirements. Afterwards, Section 5 expands on the system-engagement processes for the stakeholders, followed by Section 6 that introduces our prototype. Section 7 provides an discussion and an analysis of related projects. Finally, Section 8 concludes this work and provides an outlook on future work.

2 Technical Background and Supplementary Literature

The following section provides background information and describes related works regarding previous ideas and concepts that focus on a blockchain-based VANET platforms. First, Section 2.1 introduces the general concepts of blockchain technology, terms and frameworks. Afterwards, Section 2.2 and Section 2.3 focus on the fundamentals of autonomous vehicles as well as vehicular ad-hoc networks.

2.1 Blockchain Technology

As the name suggests, a blockchain consists of a chronologically ordered chain of blocks. Every block consists of a certain number of validated transactions and each of those block links to its predecessor by a hash reference. As a result, changing the content of one block also changes all succeeding blocks and hence breaks the chain. All blocks are stored on and verified by all participating nodes. While the initial Bitcoin blockchain only supported a very limited set of scripting instructions, the next generation of blockchain platforms, e.g., Ethereum [21], Qtum [7], or Tezos [11], provide Turing-complete programming languages on the protocol-layer level in order to enable smart contract capabilities. Smart contracts are "orchestration- and choreography protocols that facilitate, verify and enact with computing means a negotiated agreement between consenting parties" [7]. Hence, the entities participating in the enactment of a smart contract establish binding agreements and deploy applications using such smart contracts in order to provide blockchain-based applications. Those application are as versatile as smart contracts itself and enable services including the finance sector [15][18], academic and business authentication and identity solutions [3][6][12][14][19], reputation systems [4] as well as platforms for Internet-of-Things (IoT) applications [5][16].

The blockchain concept is particularly interesting for the V2X economy for three reasons. First, it removes the need for trusted third parties and instead enables trust-less transaction enactment. Second, transactions that were agreed up on cannot be changed later on since the underlying blockchain is tamperproof. Third, no human interaction is required for any kind of transaction between vehicles or machines in general.

2.2 Autonomous Vehicles

Throughout the last 15 years research on autonomous and self-driving cars progressed a lot and nowadays such cars already operating on public streets on a regular base, e.g., Tesla, Waymo and Uber. The ultimate goal of most manufacturers and researchers is to develop the first fully self-driving and autonomous vehicle. In order to clarify some definitions, this section provides a short introduction to the most relevant terms and concepts.

An autonomous car, also referred to as a driverless car or robotic car, is able to navigate and interact with its environment without human input based on information provided by its sensors [10][20]. To do so, modern cars are equipped with radar- and laser sensors, lidars, GPS devices, cameras and several further sensing devices. Based on these information, the vehicle interprets the surrounding world and deduces appropriate action strategies such as avoiding obstacles (other vehicles, humans or a house) on the way to the destination [8][22]. As the technology developed over time, vehicles were equipped with more and more sensors, resulting in different driving capabilities. The SAE [17] defined six levels of driving autonomy to categorize the varying capabilities and progresses of several approaches:

- **Level 0 (No automation):** No driving autonomy, the driver has to perform all driving tasks and interactions.
- **Level 1 (Driver assistance):** The vehicle is controlled by the driver, but is supported by some basic driver assistance functionalities.
- **Level 2 (Partial automation):** The vehicle is able to perform some specific tasks (acceleration or steering) without driver input. Nevertheless, the driver must be fully engaged in driving task and monitor all decision of the car and the environment at all time. The user has to be able to intervene at any given moment.
- **Level 3 (Conditional automation):** The driver is still a necessity, but is not required to monitor the vehicle or the environment at any given moment. But given a notification by the vehicle, the driver has to be able to take back control over the car in case the vehicle encounters a situation that it cannot deal with on its own.
- **Level 4 (High automation):** The vehicle is able to perform all driving tasks without human intervention in most driving scenarios. The driver can take control whenever desired.
- **Level 5 (Full automation):** The vehicle is able to perform all driving tasks without human intervention in all driving scenarios. The driver can take control whenever desired as long as a steering wheel is still part of the vehicle.

The Chorus interaction- and transaction layer supports and enables a varying number of services for vehicles of each automation level, whereas the most sophisticated applications require SAE level 5 and simpler plug-ins may only require SAE level 0.

2.3 Vehicular Ad-Hoc Networks - VANETs

Communication between vehicles, road infrastructure and Internet-based services is a key enabler for the upcoming generation of vehicles. So called vehicular ad-hoc networks provide an abstract concept that models the different components that are required for V2V, V2I, or V2X communication. Figure 1 illustrates the main components of VANETs: Vehicles, on-board-units (OBUs), application-units (AUs) and road-side-units (RSUs).
RSUs are placed along the road side or in dedicated locations such as at crossroads. Typically, RSUs provide short range communication based on IEEE 802.11p radio technology but can also be equipped with other network devices in order to provide communication within the infrastructural network [1]. OBUs are mounted onto a vehicle and used for data exchange. To do so, short range wireless- or radio communication is used to exchange these information [2]. Closely linked to the OBU is the AU, they might even reside in the same physical unit or as a mobile until that is regularly removed from the vehicle (e.g smartphones). The AU provides an execution environment for applications that utilize the OBU's communication capabilities [1][2].

Communication in VANETs occurs either inside a vehicle between AUs and

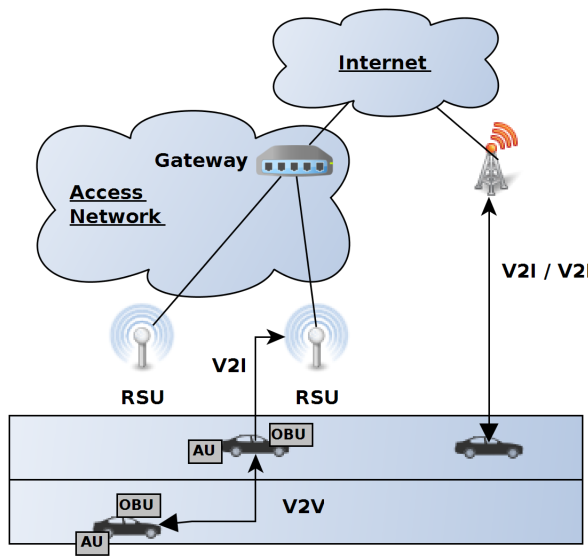

Fig. 1. General VANET architecture (Based on [2] and [13])

OBU, wirelessly between different vehicles (V2V), vehicles and infrastructure (V2I) or vehicles and the infrastructure via broadband (V2B) [9]. For authentication purposes, each network participant is equipped with a unique public/private key pair that resides in a tamper-proof-device (TPD). In blockchain terms, the TPD is similar to an external hardware wallet.

3 Section 3

4 Section 3

5 Section 5

6 Section 6

7 Section 7

8 Conclusion and Future Work

References

1. Al-Sultan, Saif and Al-Doori, Moath M and Al-Bayatti, Ali H and Zedan, Hussien: A Comprehensive Survey on Vehicular Ad Hoc Network. Journal of Network and Computer Applications 37, 380–392 (2014)

2. Baldessari, R., Bödekker, B., Deegener, M., Festag, A., Franz, W., Kellum, C.C., Kosch, T., Kovacs, A., Lenardi, M., Menig, C., et al.: Car-2-Car Communication Consortium - Manifesto (2007)
3. Bochem, A., Leiding, B., Hogrefe, D.: Unchained Identities: Putting a Price on Sybil Nodes in Mobile Ad hoc Networks. In: Security and Privacy in Communication Networks (SecureComm 2018). Singapore (August 2018)
4. Calcaterra, C., Kaal, W.A., Vlad, A.: Semada Technical Whitepaper - Blockchain Infrastructure for Measuring Domain Specific Reputation in Autonomous Decentralized and Anonymous Systems. URL: `https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3125822` (2018), (Accessed April 18, 2018)
5. Christidis, K., Devetsikiotis, M.: Blockchains and Smart Contracts for the Internet of Things. IEEE Access 4, 2292–2303 (2016)
6. Civic Technologies, Inc.: CIVIC - Whitepaper. URL: `https://tokensale.civic.com/CivicTokenSaleWhitePaper.pdf` (2017), (Accessed May 01, 2018)
7. Dai, P., Mahi, N., Earls, J., Norta, A.: Smart-Contract Value-Transfer Protocols on a Distributed Mobile Application Platform. URL: `https://qtum.org/uploads/files/a2772efe4dc8ed1100319c6480195fb1.pdf` (2017), (Accessed May 01, 2018)
8. Dokic, J., Müller, B., Meyer, G.: European roadmap smart systems for automated driving. European Technology Platform on Smart Systems Integration (2015)
9. Faezipour, M., Nourani, M., Saeed, A., Addepalli, S.: Progress and Challenges in Intelligent Vehicle Area Networks. Communications of the ACM 55(2), 90–100 (2012)
10. Gehrig, S.K., Stein, F.J.: Dead reckoning and cartography using stereo vision for an autonomous car. In: Intelligent Robots and Systems, 1999. IROS'99. Proceedings. 1999 IEEE/RSJ International Conference on. vol. 3, pp. 1507–1512. IEEE (1999)
11. L. M. Goodman: Tezos - A Self-Amending Crypto-Ledger (White paper). URL: `https://www.tezos.com/static/papers/white_paper.pdf` (2014), (Accessed April 27, 2018)
12. Leiding, B., Cap, C.H., Mundt, T., Rashidibajgan, S.: Authcoin: Validation and Authentication in Decentralized Networks. In: The 10th Mediterranean Conference on Information Systems - MCIS 2016. Cyprus, CY (September 2016)
13. Leiding, B., Memarmoshrefi, P., Hogrefe, D.: Self-Managed and Blockchain-Based Vehicular Ad-Hoc Networks. In: Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct. pp. 137–140. ACM (2016)
14. McCorry, P., Shahandashti, S.F., Clarke, D., Hao, F.: Authenticated key exchange over bitcoin. In: International Conference on Research in Security Standardisation. pp. 3–20. Springer (2015)
15. Nguyen, Q.K.: Blockchain - A Financial Technology for Future Sustainable Development. In: Green Technology and Sustainable Development (GTSD), International Conference on. pp. 51–54. IEEE (2016)
16. Ouaddah, A., Elkalam, A.A., Ouahman, A.A.: Towards a Novel Privacy-Preserving Access Control Model Based on Blockchain Technology in IoT. In: Europe and MENA Cooperation Advances in Information and Communication Technologies, pp. 523–533. Springer (2017)
17. SAE International: Automated Driving - Levels of Driving Automation as Defined in SAE International Standard J3016. URL: `https://web.archive.org/web/20170903105244/https://www.sae.org/misc/pdfs/automated_driving.pdf` (2014), (Accessed May 01, 2018)

18. SALT Technology, Ltd.: SALT - Blockchain-Backed Loans - Whitepaper. URL: `https://membership.saltlending.com/files/abstract.pdf` (2017), (Accessed April 25, 2018)
19. SelfKey Foundation: SelfKey - Whitepaper. URL: `https://selfkey.org/whitepaper/` (2017), (Accessed April 27, 2018)
20. Thrun, S.: Toward robotic cars. Communications of the ACM 53(4), 99–106 (2010)
21. Wood, G.: Ethereum: A Secure Decrentralized Generalised Transaction Ledger. URL: `http://gavwood.com/paper.pdf` (2014), (Accessed May 01, 2018)
22. Zhu, W., Miao, J., Hu, J., Qing, L.: Vehicle detection in driving simulation using extreme learning machine. Neurocomputing 128, 160–165 (2014)