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IoT Driven Technology: V2V Delay Tolerant Data Distribution Product Analysis for a Connected Vehicle Startup

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Escola de Engenharia

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DIREITOS DE AUTOR E CONDIÇÕES DE UTILIZAÇÃO DO TRABALHO POR TERCEIROS

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"Sê todo em cada coisa. Põe quanto és no mínimo que fazes."

Fernando Pessoa

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Resumo

Tecnologia Derivada da Internet das Coisas (IoT): Análise de Produto da disseminação de dados para comunicação Veículo-para-Veículo (V2V) tolerante a atrasos para uma startup de veículos conectados

A Internet das Coisas (IoT) é uma rede conectada de dispositivos que comunicam entre si, com a capacidade de constantemente partilhar dados sem necessitar de intervenção humana. A IoT aplicada aos veículos é a base para a criação das cidades inteligentes e de um futuro onde os veículos estão constantemente conectados e a comunicar entre si através da comunicação Veículo-para-Veículo (V2V), através de Wi-Fi, DSRC, rede celular (que inclui 5G) ou C-V2X. Portanto, a mobilidade está a ser redesenhada para um negócio de mobilidade como serviço (MaaS), que é expectavel em breve ser totalmente conectada, autónoma, partilhada e elétrica, aumentando a segurança e a qualidade de experiência dos passangeiros, uma vez que cada vez menos será necessário o contributo do motorista.

A Veniam emerge como criadora da "Internet das Coisas que se Movem", utilizando Wi-Fi na comunicação veicular, resultando numa solução económica para as necessidades crescentes de consumo de dados. Apesar da indústria ainda não saber claramente qual o caminho a seguir na comunicação veicular, atualmente é altamente dependente em soluções dispendiosas de rede celular. Assim, esta dissertação tem como foco a análise de produto do Vehicle-to-Vehicle (V2V) tolerante ao atraso, sem finalidade para segurança veicular. Teoricamente, foi realizada uma revisão de literatura e crítica análise de mercado relacionada com o contexto atual, as necessidades de dados para a conectividade entre os veículos, os custos e como a Veniam se posiciona em relação à sua competição, de forma a caracterizar os requisitos atuais, tanto para os fabricantes de equipamentos originais (OEMs) como para os clientes finais; Na prática, foi realizada uma simulação de redes de veículos utilizando o Julia (.jl) para entender o impacto das estratégias de fragmentação, disseminação e tamanho do ficheiro no comportamento da disseminação por V2V (%) e adaptabilidade ao produto. De forma a resumir os resultados teóricos e práticos, os dados encontram-se compilados numa dashboard de visualização de dados, realizada em PowerBI. Os resultados foram usados para testar se existe uma utilização real do mercado para a solução V2V da Veniam, onde foi concluído que a tecnologia é capaz de satisfazer cenários onde as aplicações são tolerantes a atrasos. No geral, a dissertação afirma que, para aplicações V2V tolerantes ao atraso, o produto da Veniam satisfaz as necessidades dos consumidores, tanto em termos de eficiência como de custo, sendo aconselhada uma pesquisa constante, de forma a manter uma vantagem competitiva sustentada.

Palavras-Chave: Através do ar; Internet das Coisas; Veículo-para-Veículo; Tolerante a Atrasos.

Abstract

IoT Driven Technology: V2V Delay-Tolerant Data Distribution Product Analysis for a Connected Vehicle Startup

Internet of Things (IoT) is a connected network of devices that communicate seamlessly with each other, with the ability to share data without requiring human interaction. IoT applied in vehicles is the basis for the development of smart cities and a future where vehicles are constantly connected and communicating with each other via V2V, either via Wi-Fi, DSRC, broadband cellular networks (that include 5G) and C-V2X. So, mobility is reshaping towards a Mobility as a Service (MaaS) business, soon expected to be fully CASE (Connected, Autonomous, Shared, and Electrical) increasing its safety and passengers' quality of experience since fewer tasks are expected from the driver.

Veniam, an 8-year old tech startup, emerges as the creator of the "Internet of Moving Things" levering the available Wi-Fi networks in vehicular communication, allowing cost-effective results for the increasing data needs. Albeit the industry has no clear path on how the vehicles will communicate, currently it is highly dependent on costly cellular solutions (3G/4G). This dissertation focuses on analysing one of Veniam's technological products: V2V Delay Tolerant for non-safety applications. As the current market focuses on high-priority safety applications using mainly cell communications, Veniam possesses a temporary competitive advantage, since there is not yet a lot of research done in the field. Hence, an extensive product analysis is made. For the theoretical part, together with the literature review on most recent technologies for the vehicle communication system and connectivity, a critical market analysis is performed related to the automotive landscape, vehicle connectivity data needs, data costs and where Veniam positions itself among the competitors, understanding the current trends, needs, and requirements both for the Original Equipment Manufacturers (OEMs) and end-customers. For the practical part, a vehicular simulation using Julia (.jl) is carried to understand the impact of the file size, chunking and seeding strategies on the behavior of the V2V Offload (%) and adaptability to the product, where the experiments were carried both for file fragmentation and replication. To compile the insights from the theoretical and practical aspects, the results are showcased in a data visualisation PowerBI dashboard. The retrieved results were used to test if there is an actual market fit for the Veniam's V2V solution, where the conclusions are encouraging since it was proved that the technology is capable of fulfilling delay-tolerant use cases. Overall, the thesis states that for V2V Delay Tolerant applications, the Wi-Fi leveraging of underused capacity in the product highly satisfies the stakeholders' needs, both efficiency and costly wise, being advised to Veniam constant research around this ingenious topic to maintain a sustained competitive advantage.

Keywords: Content Distribution; Delay Tolerant; Internet of Things; Over the Air; Vehicle-to-Vehicle.

Contents

1 Introduction **1**

1.1 Background . . . 1

1.2 Veniam . . . 3

1.3 Problem definition . . . 5

1.4 Goals . . . 6

1.5 Research methodology . . . 7

1.6 Thesis outline . . . 8

2 Literature review **10**

2.1 Internet of Things . . . 10

2.1.1 Smart Cities . . . 12

2.1.2 Connected Vehicle . . . 13

2.2 Vehicular communication system . . . 13

2.2.1 Vehicle to Vehicle (V2V) . . . 15

2.2.1.1 Non-safety enabled applications by V2V . . . 17

2.2.1.2 Seeding strategy . . . 17

2.2.1.3 Chunking . . . 21

2.3 Technology for vehicle connectivity . . . 22

2.3.1 Wi-Fi . . . 22

2.3.2 DSRC . . . 24

2.3.3 Broadband cellular network technologies . . . 25

2.3.3.1 5G . . . 26

2.3.4 C-V2X . . . 27

2.4 Reflection upon literature review findings . . . 29

3 Case description and critical analysis **31**

3.1 Automotive Landscape . . . 32

3.1.1 Automotive Evolution . . . 32

3.1.1.1 Connected Vehicles (CV) . . . 32

3.1.1.2 Autonomous Vehicles (AV) . . . 34

3.1.1.3 Shared Vehicles (SV) . . . 36

3.1.1.4 Electric Vehicles (EV) 38
3.1.2 Supply Chain in the context of software integration on automotive industry . . . 39
3.1.2.1 Tier-1 40
3.1.2.2 OEM 41
3.1.2.3 Software Integration 42
3.1.2.4 Challenges and opportunities faced in the automotive ecosystem . . 43
3.2 Vehicle connectivity data needs 44
3.2.1 The V2V ecosystem 44
3.2.2 Data volume per consumption 45
3.2.2.1 Moving and Stationary 45
3.2.2.2 Delay-tolerant and high-priority 47
3.2.2.3 Car-specific vs fleet data 47
3.2.2.4 Applications needs 48
3.3 Vehicle connectivity data costs 49
3.3.1 Cellular 49
3.3.2 Wi-Fi 50
3.3.3 Comparison 51
3.4 Veniam Positioning 52
3.4.1 Product description 52
3.4.1.1 Dashboard for OEMs 52
3.4.1.2 In-vehicle dashboard 54
3.4.2 Business benefits 55
3.4.3 Customer analysis 56
3.4.3.1 Targeted customer 57
3.4.3.2 Needs of the customer 57
3.4.4 Competitive landscape 58
3.4.4.1 Direct competition 59
3.4.4.2 Indirect competition 59
3.4.4.3 Partnership 60
3.4.5 Financial analysis 61
3.4.6 Strategic fit 63
3.4.7 Conclusion on V2V market fit 63

3.5 Reflection on the Product Analysis . . . 64

4 Methodology **66**

4.1 Product terminology on V2V . . . 66

4.2 Simulation . . . 67

4.2.1 Testbed description . . . 67

4.2.2 Assumptions . . . 68

4.2.3 Seeding strategies . . . 69

4.2.4 Programming environment . . . 69

4.2.4.1 Parameters . . . 69

4.3 Use cases . . . 71

4.3.1 Impact of file fragmentation amongst seeder vehicles . . . 72

4.3.2 Impact of file replication amongst seeder vehicles . . . 74

4.4 Test case description . . . 76

5 Results **78**

5.1 E1: Impact of file fragmentation amongst seeders . . . 78

5.1.1 100MB . . . 78

5.1.1.1 Strategies overview . . . 78

5.1.1.2 Cost overview . . . 81

5.1.1.3 Chunk size comparison . . . 83

5.1.1.4 Test repetition overview . . . 84

5.1.1.5 Conclusion on 100MB file fragmentation . . . 86

5.1.2 1GB File . . . 89

5.1.2.1 Strategies overview . . . 89

5.1.2.2 Cost overview . . . 92

5.1.2.3 Conclusion on 1GB file fragmentation . . . 92

5.1.3 Overall reflection on file fragmentation experiment (E1) . . . 94

5.2 E2: Impact of file replication amongst seeders . . . 96

5.2.1 100MB File . . . 96

5.2.1.1 Percentage of file seeded file fleet-wide . . . 98

5.2.1.2 Cost overview . . . 99

5.2.1.3 Conclusion on 100MB file replication . . . 100

5.2.2 1GB File . . . 102
5.2.2.1 Percentage of seeded file fleet-wide . . . 104
5.2.2.2 Cost overview . . . 105
5.2.2.3 Conclusion on 1GB file replication . . . 106
5.2.3 Overall reflection on the file replication experiment (E2) . . . 107
5.3 Comparison between file fragmentation (E1) and replication (E2) . . . 108
5.4 V2V data cost dashboard . . . 111
5.4.1 Filters . . . 112
5.4.2 Costs overview . . . 112
5.4.3 Ideal parameters outcome . . . 113
5.4.4 Monthly and yearly savings . . . 114
5.4.5 Data questions . . . 114

6 Conclusion 115
6.1 Implementation . . . 115
6.2 Critical analysis on key findings . . . 116
6.3 Risks and contingency plan . . . 117
6.4 Future work . . . 118

A Demonstration for stakeholders 128

B Worldwide Cellular Cost 129

C Worldwide Wi-Fi Cost 135

D Veniam's entire competitive landscape 140

E Complete Simulation Results 143
E.1 Results of E1 for 100MB file with 10 repetitions . . . 143
E.2 Results of Experiment 1 for 100MB file with 20 repetitions . . . 144
E.3 Results of Experiment 1 for 1GB file with 10 repetitions . . . 145
E.4 Results of Experiment 1 for 1GB file with 20 repetitions . . . 146
E.5 Results of Experiment 2 for 100MB file with 10 repetitions . . . 147
E.6 Results of Experiment 2 for 1GB file with 10 repetitions . . . 148

Acronyms

3GPP Third Generation Partnership Project.

5GAA 5G Automotive Association.

ADAS Advanced driver-assistance systems.

APs Access Points.

AV Autonomous Vehicle.

BSM Basic Safety Messages.

C-V2X Cellular vehicle-to-everything.

CV Connected Vehicle.

DSRC Dedicated Short-Range Communication.

EAP Extensible Authentication Protocol.

EV Electric Vehicle.

FCC Federal Communications Commission.

GPS Global Positioning System.

I4.0 Industry 4.0.

ICT Information and Communication Technology.

IEEE Institute of Electrical and Electronics Engineering.

IMT International Mobile Telecommunications.

IoT Internet of Things.

IP Intellectual Property.

ITS Intelligent Transportation System.

LTE Long Term Evolution.

MaaS Mobility-as-a-Service.

NC Network Coding.

NFC Near-field communication.

NOC Network Operation Control.

nseeder Number of Seeders.

OBU On Board Unit.

OEMs Original Equipment Manufacturers.

OTA Over The Air.

PFPS Percentage of file per seeder.

PSK Pre Shared Keys.

QoS Quality-of-Service.

RFID Radio-Frequency Identification.

RSS Random Short Strategy.

RSU Road Side Units.

SC Smart City.

TTFB Time to First Byte.

V2C Vehicle-to-Cloud.

V2D Vehicle-to-Device.

V2G Vehicle-to-Grid.

V2I Vehicle-to-Infrastructure.

V2P Vehicle-to-Pedestrian.

V2R Vehicle to Roadside.

V2V Vehicle-to-Vehicle.

V2X Vehicle-to-Everything.

VANETs Vehicular ad hoc networks.

WAVE Wireless Acess in Vehicular Environments.

WISPr Wireless Internet Service Provider roaming.

WLAN Wireless Local Access Networks.

WPA Wi-Fi Protected Access.

List of Figures

1.1 Veniam solution for mobile data offload (Veniam, 2020) 4
1.2 Veniam connected car used for demonstrations to costumers (Veniam, 2020) 5

2.1 Global Share of IoT projects (IoT Analytics, 2018) 12
2.2 Smart City policy intensity (Caragliu and Del Bo, 2019) 13
2.3 Best dissemination strategies with 10, 50 and 100 seeders (Kershaw and Krishnamachari, 2015) 20
2.4 Seed selection using SIEVE (Mezghani et al., 2016) 21
2.5 Dedicated Short-Range Communication (DSRC) spectrum map (Naik et al., 2017) 24

3.1 Issue tree to map V2V readiness 31
3.2 Expectation of connectivity vehicle level (%) by 2030 (McKinsey, 2019a) 34
3.3 McKinsey's 2017 consumer survey indicates shared mobility should see further growth (McKinsey, 2017) 37
3.4 Electric vehicle sales growth (PwC, 2018) 38
3.5 V2V content distribution 45
3.6 Stationary use case: V2V parking lot (left: updating software individually via cell; right: updating software via Wi-Fi V2V) 46
3.7 Moving in opposite directions use case 46
3.8 Wi-Fi worlwide prices, (Cable.co.uk, 2020a) 51
3.9 Veniam's NOC 53
3.10 Veniam's NOC V2V 53
3.11 Veniam's policy creation 54
3.12 Veniam's V2V in-Vehicle dashboard 54
3.13 Veniam's stakeholders relation and value proposition 58
3.14 Strengths, Weaknesses, Opportunities and Threats to Veniam's V2V Product 60
3.15 Data source utilisation impacts data costs 61
3.16 Savings on data using Veniam's solution Wi-Fi + V2X 61

4.1 V2V time sequence of connection and offload 67
4.2 Simulation test scheme 72
4.3 File fragmentation amongst seeder vehicles 73

4.4 File replication amongst seeder vehicles . . . 76

5.1 V2V Offload (%) of Experiment 1 for 100MB - random strategy . . . 79
5.2 V2V Offload (%) of Experiment 1 for 100MB - weighted strategy . . . 80
5.3 V2V Offload (%) of Experiment 1 for 100MB - FCFS strategy . . . 81
5.4 Optimistic, realistic and pessimistic cost view for the file fragmentation of a 100MB file . 82
5.5 Chunk size comparison (1MB, 5MB and 10MB) for 100MB File for 1, 2 and 4 seeders . 83
5.6 Comparison of V2V Offload (%) of Experiment 1 (100MB) with 10 and 20 repetitions for the random strategy . . . 85
5.7 Comparison of V2V Offload (%) of Experiment 1 (100MB) with 10 and 20 repetitions for the weighted strategy . . . 86
5.8 Comparison of V2V Offload (%) of Experiment 1 (100MB) with 10 and 20 repetitions for the FCFS strategy . . . 86
5.9 V2V Offload (%) of 100MB file fragmentation per seeding strategy . . . 87
5.10 V2V Offload (%) of 100MB file fragmentation per seeding strategy (Proportional View) . . 88
5.11 V2V Offload (%) of Experiment 1 for 1GB - random strategy . . . 89
5.12 V2V Offload (%) of Experiment 1 for 1GB - weighted strategy . . . 90
5.13 V2V Offload (%) of Experiment 1 for 1GB - FCFS strategy . . . 91
5.14 Cost view for file fragmentation of a 1GB File . . . 92
5.15 V2V Offload (%) of 1GB file fragmentation per seeding strategy . . . 93
5.16 V2V Offload (%) of 1GB file fragmentation per seeding strategy - proportional view 93
5.17 Comparison of the V2V offload (%) of the file fragmentation of the 100MB and 1GB file . 94
5.18 Offload Growth per nseed in E2 (100MB) . . . 97
5.19 Percentage of file seeded fleet-wide (%) (100MB) . . . 98
5.20 Percentage of file seeded fleet-wide compared with V2V Offload (%) (100MB) . . . 99
5.21 Savings of the maximum V2V offload (%) per Number of seeders (nseeder) (100MB) . . 100
5.22 Offload Growth per nseeder in E2 (1GB) . . . 103
5.23 Percentage of file seeded fleet-wide (%) (1GB) . . . 104
5.24 Percentage of file seeded fleet-wide compared with V2V Offload (%) (1GB) . . . 105
5.25 Savings of the maximum V2V offload (%) per nseeder (1GB) . . . 106
5.26 Comparison of the V2V Offload (%) of the file replication of the 100MB and 1GB files . . 107
5.27 Comparison between V2V offload (%) of E1 and E2 for 100MB file . . . 109
5.28 Comparison between savings of E1 and E2 for 100MB file . . . 109

5.29 Comparison between offload of E1 and E2 for 1GB file 110
5.30 Comparison between savings of E1 and E2 for 1GB file 110
5.31 V2V data cost dashboard 111
5.32 Filters 112
5.33 Costs overview 113
5.34 Insights of the ideal outcome to be implemented in the network 113
5.35 Monthly and yearly view of predicted and actual savings 114

6.1 VRIO analysis 116

A.1 Demonstration of Veniam's software made to stakeholders 128

List of Tables

2.1 V2V safety applications examples, (Harding et al., 2014) 15
2.2 Future vehicular communications needs (Arena and Pau, 2019) 16

3.1 Autonomy level evolution by year and market type (PwC, 2019) 36
3.2 Delay-tolerant applications data needs with maximum delay 48
3.3 High-priority application data needs with data rates and latency 49
3.4 Summarised Product Analysis 65

4.1 Product terminology on V2V 66
4.2 Seeding strategies description 69
4.3 Experiment 1 - Percentage of file per seeder (PFPS) per nseeder (100MB) 72
4.4 Experiment 1 - PFPS per nseeder (1GB) 73
4.5 Experiment 2 - PFPS per nseeder (100MB) 74
4.6 Experiment 2 - PFPS per nseeder (1GB) 75

5.1 Experiment 1 - Results of random strategy (100MB) 79
5.2 Experiment 1 - Results of weighted strategy (100MB) 80
5.3 Experiment 1 - Results of FCFS strategy (100MB) 81
5.4 Cost overview for the file fragmentation of a 100MB file 82
5.5 Experiment 1 - Results of random strategy (1GB) 89
5.6 Experiment 1 - Results of weighted strategy (1GB) 90
5.7 Experiment 1 - Results of FCFS strategy (1GB) 91
5.8 Cost overview for the file fragmentation of a 1GB file 92
5.9 Highlights of Experiment 1 - File fragmentation amongst seeder vehicles 95
5.10 Results of Experiment 2 - File replication amongst seeders (100MB) 96
5.11 Results of Experiment 2 - File replication amongst seeders (1GB) 102
5.12 Highlights of Experiment 2 - File replication amongst seeder vehicles 108

B.1 Worldwide Cellular Cost (Cable.co.uk, 2020b) 129

C.1 Worldwide Wi-Fi Package Cost (Cable.co.uk, 2020a) 135

D.1 Veniam's entire competitive landscape 140

E.1 Results of Experiment 1 for 100MB file with 10 repetitions 143
E.2 Results of Experiment 1 for 100MB file with 20 repetitions 144
E.3 Results of Experiment 1 for 1GB file with 10 repetitions 145
E.4 Results of Experiment 1 for 1GB file with 20 repetitions 146
E.5 Results of Experiment 2 for 100MB file with 10 repetitions 147
E.6 Results of Experiment 2 for 1GB file with 10 repetitions 148

Chapter 1

Introduction

The present dissertation falls under the scope of the Masters in Industrial Engineering and Management at the University of Minho. The thesis was developed throughout an internship in Veniam, a technology startup with an Intelligent Networking Platform that moves high amounts of data between connected vehicles and the cloud (Veniam, 2020).

This section aims to provide a background, an overview of the company, the problem definition for the dissertation, the goals, the used research methodology for the problem conception, and the overall document structure.

1.1 Background

Technology has been predominant in everyday life and has been evolving for the past years. The latest technological upgrade accompanies Industry 4.0 (I4.0) which represents the fourth industrial revolution. This shift was mainly originated due to the emergence of the Internet (Bisio et al., 2018), having an outstanding impact on communication.

While in the past people were communicating with each other through the Internet, today with the IoT (adding to the people communication) devices are the ones communicating with each other. Thus, according to Feng et al. (2012) IoT will increase the worldwide presence of the Internet, due to the integration of every object for interaction via embedded systems, creating a network of interconnected everyday gadgets communicating with each other and with human beings. So, known as the machine-to-machine networking, IoT is becoming a reality where everyone and everything has a seamless internet connection, having been estimated to become a $19 trillion business opportunity in the next decade (Zhidanov et al., 2019).

Moreover, with IoT generating more and more data, many activities in diverse fields are updating. Hence, the function of collecting, analysing, and processing such big data will generate new understandings and development of applications enabled by IoT (Deloitte, 2015). Bandyopadhyay and Sen (2011) consider IoT can impact several areas, such as in aerospace and aviation (e.g.: examining the requirements of the unapproved parts of air crafts, preventing accidents and incidents), in medicine and healthcare (e.g.: usage of Radio-Frequency Identification (RFID) to monitor medical parameters and drug delivery), in manufacturing (e.g.: linking items with information technology, gaining a clear perception of the status of the shop floor, mostly regarding the production machines) and in the supply chain (e.g.: mainly using RFID items and smart shelves that track the items in real-time).

Besides the above-mentioned applications, one of the most relevant development nowadays is in the automotive and telecommunication industries, which are facing challenges regarding this I4.0 industrial transition. Bandyopadhyay and Sen (2011) believe that the DSRC technology, which is an open-source protocol for wireless communication specifically designed for automotive usage, will impact the most the technology advancement by reducing interference with other equipment. This advantage allows vehicles to communicate seamlessly with one another, which is possible due to the enhancement of possible connections of the various vehicle electronic components with a centralized server, along with the hardware installment. Though, besides DSRC, other technologies may have a better fit for vehicular communication.

Hence, soon, personal and public transportation will compose a mesh network, where they steadily communicate with each other and the cloud. So, with half of the world's population living in urban areas, and expecting to increase its accommodation in an additional 2.5 billion people over the next three decades (Reuters, 2014), currently, there is the need to exploit the most advanced technologies to support added-value services for the administration of the city and the citizens (Zanella et al., 2014). Thus, by the usage of connected cars, which represent a valuable segment in IoT, cities will function as one, interacting with the various stakeholders that make the city safe and easily functional.

It is estimated that by 2022, 100% of the produced cars will be connected, requiring to move massive amounts of data (PwC, 2018). Therefore, embedded infotainment and smart vehicles that compose these mesh networks need to rely on updated information, obtained by the continuous communication with neighboring vehicles. As a result, by moving terabytes of data to and from the cloud it is granted relevant content to the vehicle operation as well as the comfort of the passengers. Cars will generate more than the amount of data that the average person generates today, therefore consuming approximately 40 terabytes of data (considering the driving time of eight hours)(Nelson, 2016). Though, on one hand, moving this massive quantity of data through cellular is utterly expensive. On the other hand, with wireless communication, it is possible to reduce communications costs.

To assure the correct performance of the mesh network, Vehicular ad hoc networks (VANETs) are used, contributing to road safety and Intelligent Transportation System (ITS) (Dimitrakopoulos and Demestichas, 2010). According to Calegari et al. (2007), VANETs are self-organized networks that are created as needed, boosted by moving vehicles and are part of a more general class of Mobile Ad-hoc Networks (MANETs).

As a matter of fact, worldwide academic institutions, industries, and governments have been developing extensive research on this topic (Zeadally et al., 2012).

Communication through VANETs is done through standards such as V2V and Vehicle to Infrastructure (V2I), which are jointly mentioned as Vehicle-to-Everything (V2X). More specifically, V2V content distribution refers to the mechanism of peer-to-peer content distribution, involving two or more vehicles, sharing files between each other in the mesh network.

According to Ye et al. (2019) new challenges are carried due to the high mobility of vehicles. For instance, due to critical safety, the Quality-of-Service (QoS) requirements for V2V are very rigorous with ultra-low latency and high reliability.

Albeit today's V2V main applications have been regarding safety information between vehicles to ease warnings to drivers concerning imminent crashes (Harding et al., 2014), there are other scenarios where the technology is used. This is where Veniam reinforces its market position, by enabling automotive OEMs to use Wi-Fi V2V Content Distribution, to cheaply transfer data between the vehicles in the fleet.

As a result, mobility is changing with technology and Veniam is contributing to its developments through research on the definition of the Internet of Moving Things™, with the #1 Data Networking Platform for Connected Vehicles and Future Mobility.

1.2 Veniam

Veniam is an 8-year old Portuguese startup with the mission of building the Internet of Moving Things™. It began as a spin-off from "Instituto de Telecomunicações" both from the University of Porto and Aveiro. Since then, it has been growing through funding. In 2014, Veniam raised $4.9 million in series A funding by True Ventures, USV and Cane Builds. In 2016, the startup raised $25 million in series B funding by investors such as Cisco, Orange, Verizon, Yamaha Motors, and Liberty Global. Furthermore, Veniam has been awarded, including being ranked as one of the top 50 most disruptive companies of 2016 and 2017, by NASDAQ and Consumer News and Business Channel (CNBC) (CNBC, 2016).

Nowadays, the company is established in Mountain View, USA, and in Porto, Portugal where the main personnel from engineering, system operations, finance, and product development is operating.

The startup has built the largest and most sophisticated worldwide mesh-network of connected vehicles, Veniam's VANET in Porto (MIT Technology Review, 2014). In contrast with the traditional wireless network infrastructure, the mesh platform considers vehicles as Access Points (APs) for Wi-fi that connect to one another and settled points (Choudhury, 2016). With this network, the startup is capable of connecting over 400 public buses, garbage collection trucks, and municipality vehicles equipped with On Board Unit (OBU) that provide wireless connectivity.

Moreover, Veniam has developed an Intellectual Property (IP) portfolio over 190 patents, software, and cloud services, which combined turn vehicles into Wi-Fi hotspots, creating the mesh network that expands wireless coverage, collects terabytes of daily urban data and delivers managed services to ITS. Veniam IP portfolio subscribes pain issues for the automotive industry, creating reliable, trustworthy, and cost-effectively solutions to OEMs that need to move a large amount of data, generating new sources of revenue (Forbes, 2018).

Recently, in 2017, Veniam changed its value proposition and customer segment, shifting its focus from hardware and software development to solely software development, from the fleet to the automotive industry. The startup believes that the upcoming autonomous driving systems will lean on mastering this type of communication, to perceive future mobility as reliable, safe, protected, and secured.

By taking advantage of multiple network interfaces and technologies such as DSRC, Wi-Fi, and Long Term Evolution (LTE), Veniam's platform is able to build an integrated vehicle ecosystem, prioritising the leverage of Wi-Fi networks. Veniam, by connecting vehicles to the Cloud through Wi-Fi, decreases the dependency on cellular communications, which are provided and debited by the telecommunications companies. To achieve high performance at a cheaper cost, the platform also manages traffic offload to prevent networks from being congested, delivering seamless handovers between technologies. Additionally, it guarantees the connectivity to the interface that best suits the current situation. Lastly, it implements local data management that decides which data should be offloaded in real-time and which data can be stored to be sent later in a delay tolerant manner. Hence, Veniam's solution compiles four main branches as shown in Figure **1.1**.

Figure 1.1: Veniam solution for mobile data offload (Veniam, 2020)

Firstly, **Connection Management** allows cars to achieve a greater connected distance and wider Wi-Fi coverage than the default connection manager used by major OEMs while expanding multi-network connection management easily to Cellular vehicle-to-everything (C-V2X) and 5G as needed. Secondly, **Data Management** contributes to assure that each application has the available networking resources for its individual requirements, guaranteeing that there's an excellent match between the communication capabilities with application data requirements. Thirdly, **Policy Management** smoothly sets global policies in the Cloud that get automatically translated to vehicle decisions, controlling data prioritisation for different applications. Fourthly, **Provider Management** grants that all vehicles have the correct Wi-Fi credentials for all APs at the right time (Veniam, 2020).

All in all, by using Veniam's solution, the automotive OEMs are able to collect and share data in a more cost-efficient way, prioritizing Wi-Fi over cellular vehicular communication in a seamless way. Therefore, the startup is developing essential enablers for the vision of Smart City (SC) contributing to safer streets, reduced traffic, cleaner air, and more open space (Costa, 2018) and a more connected mobility as demonstrated in Figure **1.2**.

Figure 1.2: Veniam connected car used for demonstrations to costumers (Veniam, 2020)

1.3 Problem definition

By investing six months in the master thesis internship at Veniam (in the Product Management team), the end goal of the project is to prove the value of a newly developed Vehicle-to-Vehicle (V2V) Wi-Fi enabled technology applied to delay-tolerant non-safety applications in the automotive industry. The results are as well used by Veniam to showcase the potential of the technology to multinational companies.

The project shall bring impact both to the startup and OEMs. On Veniam's side, by developing an extensive literature review, research and critical analysis on the work developed by key actors in the automotive industry, one is creating a competitive advantage by enabling the development of future potential and ready-to-use technology, leveraging the underutilised Wi-Fi potential for V2V communication. The research approach begins with an extensive information collection inside the company and then benchmark Veniam's solution with other similar offers in the market. After the research, one is able to identify, through simulations and real-time demonstrations, the cost proof of the V2V technology, demonstrating the competitive advantage of using Veniam's solution. With this consistent product analysis, one can preview the financial impact it has in the automotive industry, identifying new market and business opportunities. On OEMs' side, by reducing the costs using the V2V technology, they can save financial resources, allowing either to have financial savings or applying the saved resources into new value-added activities to optimize the in-vehicle experience. Then, as a result of the internship, it is expected that the V2V use case's value proposition is refined, building a solid V2V Business Case. Once the business case is delivered it is part of the Veniam's Product Portfolio and can be presented with confidence to the external partners (OEMs).

1.4 Goals

The main objectives for this thesis is to understand the V2V potential applied to delay-tolerant non-safety applications, by analysing the impact of the adjustment of the technology to different scenarios to provide services that bring value both to the OEMs and the end-consumer. Therefore, this objective parcels out to five goals:

- **Goal 1:** Understand the behavior of the offload of V2V technology in different delay-tolerant scenarios depending on the file size, seeding and chunking strategies;
- **Goal 2:** Review the existing portfolio and research current work developed: Understand and map the V2V Technology Ecosystem;
- **Goal 3:** Prove Veniam's competitive advantage through V2V: Analyse the cost reduction and financial competitiveness of the technology;
- **Goal 4:** Identify the market and business opportunities, such as new services to enable new in-vehicle experiences, to enhance Veniam's position in the market;
- **Goal 5:** Develop and deliver a business case with the information mentioned in the above-mentioned goals.

The research questions for this master thesis are defined as:

RQ1:"Is Veniam's Wi-Fi V2V technology capable of satisfying customers and stakeholders' non-safety delay-tolerant vehicle connectivity future data needs?".

RQ2: "What is the ideal scenario of a mesh network for a maximum offload, taking into consideration the fragmentation/replication of chunks, the file size, the seeding and chunking strategies?"

1.5 Research methodology

The research methodology chosen for this project is the "Case Study" approach to develop and deliver a consistent business case for Veniam that involves a strategic, financial and deliverable perspective. Thus, the investigation involves a explanatory and descriptive study of the current and future status, as well as a detailed analysis of costs impact and business benefits (savings using Veniam software).

A case study is categorised as a strategy for conducting research that involves an empirical investigation of a particular contemporary phenomenon within the context of its real application (Robson, 2002). The structure of this dissertation is organised considering the research methodology utilised. Thus, the methodology steps to achieve the ultimate goal that answers the proposed research questions, follows as:

Literature Review: Firstly, the problem is identified as an extensive literature review on the recent technologies is made, aiming to provide the researcher a high depth knowledge of the current state-of-the-art of the focus topic. In this case, several bibliographic sources were used, with emphasis on scientific articles. In order to obtain accurate results, the following key words were used: Vehicle-to-Vehicle, Delay Tolerant, Non-safety, Internet of Vehicles, Internet of Things, Smart Mobility, Smart Cities, Over the Air, Content Distribution, Content Dissemination, Seeding, Chunking, VANET. The prior focus is on the innovation behind the V2V technology applied to delay-tolerant non-safety applications and automotive industry, to understand the state-of-the-art and transform them into valuable insights for Veniam. Hence, an overview of the current investigation findings regarding this technology is gathered to be considered as a starting point for the current business case.

Analysis of the current situation: At this stage of the project, it is extremely important to develop a critical analysis, with identification of the main current market problems and needs, forecasting what will be the mobility future and future user needs and pains.

Definition and planning of improvement proposals: At this point, as the theoretical part of the case is concluded, follows the research on the practical side. Techniques as brainstorming allied to the creativity of the research supported by software simulation tools (Julia(.jl)) and data visualisation tools (PowerBI) expand the horizons of the applicability of the technology with the details reviewed from the literature review and critical analysis.

Henceforth, at this stage, the simulations and data collection are performed, therefore quantifying the problem identified. To develop the project proposed, there is a need to access data to prove the technological concept. Hence, data is gathered by using simulations validated by real-world data and on-field testing in Porto. This data, collected from testbeds, is obtained through Veniam Netrider™, which is an equipment that Veniam uses for software development and field testing. On-field, it's used the "Veniamised" car or the 400 buses in Porto (from STCP – Sociedade de Transportes Coletivos do Porto) which supports Veniam's software. In Porto's office, Veniam's platform is used for simulations.

All of this collected data is subsequently analyzed to retain valuable information for recommendations. Here, statistical tools are applied to the raw data to clean the results and cluster them. At this stage, a "learn by doing" action research is performed since from the Experiment 1 (E1) valuable insights are gathered to input in Experiment 2 (E2), narrowing down the parameters used.

Recommendation: This step results in a condensation of the business case, where the project is fully developed, from a product analysis point of view, including market analysis, financial competitiveness, mapping the technology and performing the competitive advantage of the product in comparison with others offered in the market.

Evaluation and discussion of results: Lastly, all the work developed in the above mentioned topics is gathered in the report, that in this case it is considered to be the master thesis itself. Thus, the main key findings are presented, validating or not the research questions stated in the beginning of the investigation.

1.6 Thesis outline

This thesis is organised into six chapters, with the following outline:

Chapter 1 - "Introduction" unveils the purpose of the thesis, contextualising the problem and defining the main objectives to be pursued;

Chapter 2 - "Literature Review" delivers a theoretical background on relevant subjects that add value to the work developed in the delay-tolerant non-safety V2V applications;

Chapter 3 - "Case Description and Critical Analysis" details the environment of the problem, in order to understand the market fit of delay-tolerant V2V non-safety applications. At this stage, a review on the automotive ecosystem evolution and market needs is performed, as well as a review on the current V2V Veniam product with a focus in the competitive advantage, financial analysis, and strategic fit, contributing to a clear understanding on the value proposition Veniam has to deliver to its stakeholders;

Chapter 4 - "Methodology" demonstrates the methodology adopted to address the identified key issues in the data analysis of the testbed of 356 Vehicles in the city of Porto, in order to validate the V2V usage;

Chapter 5- "Results" reveals the outcome of the project. More specifically, the proof of the technology and recommendations to the company, together with a visual interface that supports data visualisation

Chapter 6 - "Conclusion" showcases the implementation aspects of the project, as well as the critical analysis of the key findings, the risks and contingency plan and the future work to be pursued to research.

Chapter 2

Literature review

Mobility, as well as technology, have been evolving for the past years. On one hand, it eases people's quality of life by having mobility means whenever and wherever they want. On the other hand, if more people drive, more accidents and human failure are willing to occur alongside with increased traffic within densely populated areas. Hence, to ease mobility safety and coordination cities are investing in Intelligent Transportation Systems (ITS), driven by the latest developments on wireless communications and computing.

According to European Comission (2018), ITS, Autonomous Vehicle (AV) and Connected Vehicle (CV) will generate large amounts of data, that have a lot of potential to the driver, but at the same time bring and additional pain point to the end-user regarding data-safety. Therefore, European Union proposed to develop a statement that guarantees privacy on access to in-vehicle data and resources, defending consumer rights and encouraging innovation and fair competition.

Thus, this chapter aims to make a bibliographical review of the concepts and tools that served as the foundation for the completion of this thesis.

In the beginning, an initial contextualization of the problem was made, considering the evolution of the industry (I4.0) and more specifically the progression on the communication and automotive industry, being IoT the stiffest core for these changes.

Thereafter, the focus was to review the existing vehicular communication systems (with a high-level focus on V2V), supported by the latest technologies (Wi-Fi, Cellular broadband network technologies, WAVE/DSRC and C-V2X), that facilitate ITS development.

Lastly, an overall reflection compiles the state-of-the-art on this peer-to-peer innovation.

2.1 Internet of Things

The industry has evolved for the past years and so has technology. The current industrial transformation is I4.0, which Bisio et al. (2018) believe was originated due to the emergence of the Internet, having an outstanding impact on communication.

Moreover, I4.0 represents the development of automation technologies and it frequently includes technologies such as cyber-physical systems (CPS), IoT and cloud computing (Lu, 2017), which are the Information and Communication Technology (ICT) pillars (Xu et al., 2018a).

More concisely, van Kranenburg (2018) believes that the most recent definition of IoT encompasses "a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'Things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network".

Even though when IoT surfaced it referred to the interconnection of gadgets using RFID technology, this concept evolved to be used with other technologies like sensors, actuators, the Global Positioning System (GPS) and mobile devices that were compatible with Wi-Fi, Bluetooth, cellular networks and Near-field communication (NFC) (Xu et al., 2018a). Also, IoT started in the context of supply chain management and evolved for diverse applications such as healthcare and transportation (Gusmeroli et al., 2010).

As a matter of fact, Feng et al. (2012) believes IoT will increase the worldwide presence of the Internet, due to the integration of every object for interaction via embedded systems, creating a network of interconnected everyday gadgets communicating with each other and with human beings, believed by Gubbi et al. (2013) to be performing at an unusual scale and rhythm. Furthermore, as reported by Zhidanov et al. (2019), IoT has been estimated to become a $19 trillion business opportunity in the next decade.

Though, IoT can be structured into different projects, such as SC, connected industry, connected building, connected car, smart energy, connected health, smart supply chain, smart agriculture, and smart retail, among others (IoT Analytics, 2018). Hence, as stated in Figure **2.1**, both SC and Connected cars are relevant topics, which are important to the current research and will be further explained in the subsections below.

So, from the literature review on IoT it is possible to infer that devices have the potential to be used in an IoT network. Thus, having an extensive large network arises privacy issues propelled by blockchain implementation. Hence, as one of the big challenges, privacy and blockchain development are the most relevant issues before a further development in IoT technology, mostly in SC and connected cars (Hassan et al., 2019).

More specifically, the IoT related to vehicle connectivity is referred to as the "Internet of Vehicles", enabling various vehicular applications and services to be in constant communication with each other (Xu et al., 2018b).

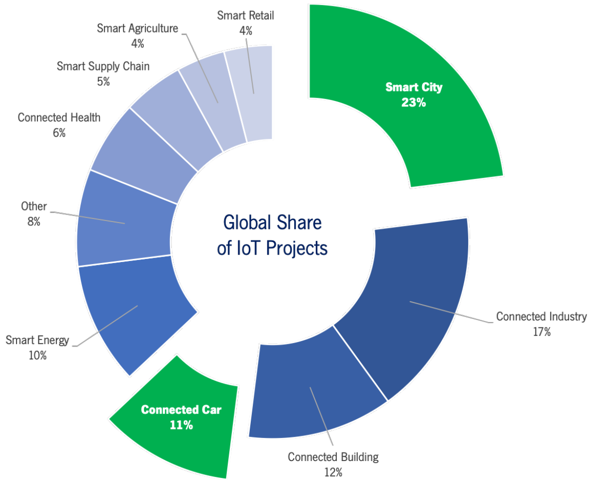


Figure 2.1: Global Share of IoT projects (IoT Analytics, 2018)

2.1.1 Smart Cities

Considered to be the major application of IoT projects, the SC concept attracts mostly local and regional administrations (Zanella et al., 2014), since most of the governments are pushing this technological update with ICT, revoking that IoT applied in the urban setting has a high range of applications and benefits (Domingue et al., 2011).

Albeit there isn't a clear concept on the definition of "smart city", as described by Zanella et al. (2014), the end goal is to use the full potential of publicly available resources, increasing the quality of services offered to citizens, while minimizing the operational expenses of the public administrations as well as incorporate modern urban production factors in a common framework (Caragliu et al., 2011). Nevertheless, the conception of SC involve structural health of buildings, waste management, air quality, noise monitoring, traffic congestion, city energy consumption, smart parking, smart lighting and automation (Zanella et al., 2014).

Albeit considered to be hard to identify what is and what isn't a SC, Caragliu and Del Bo (2019) developed an indicator of the intensity of SC policies, divided into below and above the mean of the European Union, as shown in Figure **2.2**. Thus, it can be inferred that there is a strong link between SC policies and urban innovation readiness.

Even though some questions remain still unanswered, such as "are SC facilitators of sustainability, livability and business growth?", it is proved that the presence of the creative class, dedicated attention to the metropolitan environment, the level of literacy, and the approachability to and use of ICT for public administration are all confidently correlated with urban wealth (Caragliu and Del Bo, 2019) and therefore with urban development and investment in technologies that facilitate the creation of a SC.

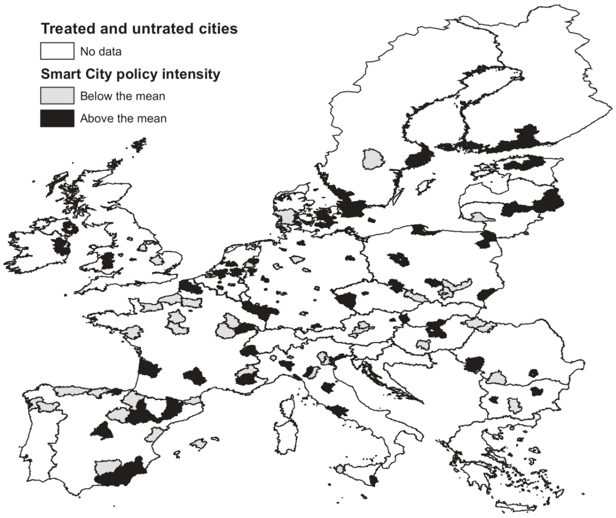


Figure 2.2: Smart City policy intensity (Caragliu and Del Bo, 2019)

2.1.2 Connected Vehicle

A connected car is by definition an IoT based concept since it is described as a vehicle that can access the Internet, communicating with other cars as well as other infrastructures and smart devices. To do so, they need to collect real-time data for various sources (Coppola and Morisio, 2016).

Most of the OEMs have embraced this concept for an innovative generation of vehicles, as some of them have proclaimed to sell driverless cars by the end of the prevailing decade or the start of the next (Coppola and Morisio, 2016) , meaning the automotive industry is shifting paradigms and embracing technological evolution on car communication.

As mentioned in the beginning of the section, one of the greatest challenges with IoT paradigm is the data privacy, which is specially applied in the connected car context, since the integration of infotainment systems with car functionalities, and their openness to third-party applications can allow malicious actors to take control of vehicles (Coppola and Morisio, 2016).

Car connectivity, besides the IoT groundwork, is a part of the "CASE": Connected, Autonomous, Shared, and Electric Vehicles. Hence, a further and more detailed market analysis regarding vehicle forecast will be made in Chapter **3**.

2.2 Vehicular communication system

For the IoT reality to happen in vehicles, and as reviewed before, cars must be connected to develop the concept of SC. Therefore, vehicles must interact with one another, as well as the cloud and the surrounding smart devices, which are delivered by the vehicular communication systems. Many are the types of vehicular communication systems: Vehicle to Cloud (V2C), Vehicle to Device (V2D), Vehicle to Grid (V2G), Vehicle to Infrastructure (V2I), Vehicle to Pedestrian (V2P), Vehicle to Roadside (V2R), Vehicle to Vehicle (V2V) and Vehicle to Everything (V2X).

According to Bitam et al. (2015), Vehicle-to-Cloud (V2C) is connecting the vehicle user with the infrastructure provider, the cloud systems, allowing vehicles to integrate IoT environments. This communication channel has high relevance for content distribution, such as updates and data purposes: predictive maintenance, usage-based insurance, and research and development applications. V2N (Vehicle to Network) is perceived to be the access to the cloud through cellular for non-critical applications, albeit it should be considered V2C. Vehicle-to-Device (V2D) has been one of the most used communications nowadays, where vehicles communicate with electronic devices. Therefore, services as car sharing are dependent on this functionality to connect to other devices (Jomaa et al., 2017). Vehicle-to-Grid (V2G) is enforced in electric vehicles, mostly since the vehicle needs to connect to the grid to request electricity (Endo and Tanaka, 2018). Vehicle to Infrastructure allows moving vehicles to interact with the road system, which oversees RFID readers, traffic lights, roadside units (RSUs), cameras, lane markers, signage, street lamps, and parking meters (Jurgen, 2012). This type of information is sent from the vehicles to the infrastructure through Ad Hoc networks (Arena and Pau, 2019). Vehicle-to-Infrastructure (V2I) applications can be perceived as a complement to V2V safety applications (Harding et al., 2014), as it will be further explained. According to Emmelmann et al. (2010), since most of the road infrastructure is still not equipped for wireless communication, V2I has intrinsically associated abundant investments by the government on hardware to push this development. Vehicle-to-Pedestrian (V2P) corresponds to individuals walking, cycling, or driving motorized two-wheelers (collectively named as Vulnerable Road Users) that highlight mostly safety purposes, where the smartphone or any connectivity device is utilized as a sensor and broadcaster of information and data (Tahmasbi-Sarvestani et al., 2017). Vehicle to Roadside (V2R) relates to the communications between the vehicles and Road Side Units (RSU). Arena and Pau (2019) support that V2X is a generalization of vehicular communication (including the above-mentioned ones) that encircles all sorts of communications involving vehicles, transferring data from a vehicle to any entity that can influence it, to establish high-bandwidth and secure connections to assist future applications and associated specifications. As this master thesis focuses on V2V communication system, deeper and extensive research is performed in the next subsection.

2.2.1 Vehicle to Vehicle (V2V)

V2V is a vehicular communication system that comprises communications between vehicles. In consonance with Vukadinovic et al. (2018), vehicles are outfitted with a diverse set of sensors, such as cameras, RADARs and LIDARs, that allow them to overview the vehicular environment around, allowing a bidirectional connection with the vehicle and any other device equipped with a suitable content dissemination module. V2V while acting as prevention to accidents, uses the data of the position and speed of the vehicle within the ad-hoc mesh network (Arena and Pau, 2019).

Arena and Pau (2019) defends the mesh network can be either fully or partially connected. In a full mesh network, each node is in direct contact with others, while in a partial some nodes can be connected to all others or connected to the ones which they exchange data the most. Here, each node can move randomly, even though wireless technology is unpredictable. This mesh network concept is only possible since the connections are made wirelessly and not via wires as made in the past, which made the process a lot more expensive and hard to execute. V2V is believed to be more effective than embedded systems currently designed by OEMs (Zeadally et al., 2019), and Harding et al. (2014) believe it can improve performance in the safety field by facilitating warnings to drivers with preventive measures to avoid human error, perceiving some threats sooner than sensors, cameras or radar can (applications that can be seen in Table **2.1**). Though, Emmelmann et al. (2010) believes that V2V depends on a notable quantity of vehicles outfitted with this functionality to thoroughly take advantage of V2V potential.

Table 2.1: V2V safety applications examples, (Harding et al., 2014)

Crash Type	**Safety Application**
Rear-End	Forward Collision Warning (FCW) and Electronic Emergency Brake Light
Opposite Direction	Do Not Pass Warning and Left Turn Assistant (LTA)
Junction Crossing	Intersection Movement Assistant (IMA)
Lane Change	Blind Spot Warning and Lane Change Warning (BSW+LCW)

Nevertheless, some other applications are being explored using V2V, including platooning (Vukadinovic et al., 2018) and content dissemination performed Over The Air (OTA) with reduced costs (Recharte et al., 2019). Yet, it is important to understand the high-level role of governments when discussing vehicular communication, especially V2V, as some of the requirements to have V2V functioning depend on governments, like the allocation of dedicated bandwidth for this type of communication (Harding et al., 2014).

All in all, the implementation of V2V on a major scale is still to be observed in the industry, due to big investment on its development and maintenance. As reported by Arena and Pau (2019) due to the nearest future being focused on ITS, the existing components and infrastructures will have to be renewed. The authors identify four features that will have an impact on the dissemination of vehicular communications, as it can be seen in the following Table **2.2.** Also, it is important to stand out the evidence that big data management is a relevant topic, where the advantages are the new economic activities and possibilities that can develop, whereas the disadvantage, as already mentioned, is the data privacy. Zeadally et al. (2019) declares that safety messages could be intercepted and changed before arriving at the main destination and driver's activities could be tracked without its consent, opening the path to external threats and hacking precedents.

Table 2.2: Future vehicular communications needs (Arena and Pau, 2019)

Feature	**Advantages**	**Downsides**
Maintenance of road surface and signs	Improvement of ITS systems performance	Economic costs
Technological Infrastructure	Full operation of V2V, V2I, and V2X communications	Complexity of large scale implementation; Standardization;
Big Data Management	Economic returns for possible private investors; More information thanks to analysis;	Ensure Data Privacy
Integration between ITS systems and technological infrastructure	Improved performance in system operation; Development of possible new future applications;	Complexity of large scale implementation; Standardization; Economic costs

Though, as for the year 2019, it is still believed that some obstacles arise in the implementation of V2V technology. Firstly, automotive OEMs need to agree with the rules of security and operation. Secondly, assuring the data privacy and confidentiality of the interchanged data. Lastly, the funds that are necessary for the development and maintenance of all technology.

OEMs such as General Motors, BMW, Audi, Daimler, and Volvo are known for the high investment in this technology (Zeadally et al., 2019). The USA has been playing a major role for past years to define experimental prototypes to investigate the environmental impact and research on the usability of vehicular applications through analytical methods (Arena and Pau, 2019).

As it can be understood, the evolution of V2V started with a high focus on safety, but is now being considered for other applications that use the data collected by the neighboring vehicles, which has yet not much literature to support upon.

2.2.1.1 Non-safety enabled applications by V2V

Platooning According to Zeadally et al. (2019), platooning emerged from the growing evolution of AVs, which consists of a group of vehicles that travel together safely, where each vehicle can communicate with the surrounding vehicles (usually forming a line), being one vehicle the platoon (the leader) that controls the performance of the neighboring fleet. Together with low fuel consumption, platooning is used mostly for trucks fleets that deliver goods and can save on transportation costs. Vukadinovic et al. (2018) also considers platooning conveys other benefits such as lower fuel consumption and efficient traffic management.

OTA updates As vehicles become more-software oriented, updating software is more critical than ever. For instance, OEMs instead of installing one by one software per vehicle manually with expensive cell solutions, can deploy the potential of V2V. The usual cellular process is slow and expensive for automotive OEMs, but if one of the various vehicles are considered “seeders”, then they can share the updates with the neighbor vehicles in a more cost-efficient way (Recharte et al., 2019).

Map updates To improve traffic efficiency, Boban et al. (2018) believe that updating the routes and dynamic digital map updates will be crucial in the near future. One vehicle updates the traffic management server via uplink each second with parameters such as location, status, and road information. This information leads to a better selection of routes, triggered by a downlink message from the traffic management server to the digital map updates. This type of data is updated regularly.

Even though the literature on non-safety applications is not extensive, there are some use cases yet to be discovered. For instance information regarding infotainment, predictive maintenance, Advanced driver-assistance systems (ADAS) features, real-time traffic, road conditions, and real-time parking information. According to Mezghani et al. (2016), vehicular networks first emerged due to safety applications, but nowadays comfort applications such as the above-mentioned ones are considered. Thus, for safety applications, the main constraint is time, whereas for comfort applications the need is to focus on user convenience and propose different metrics to evaluate users’ satisfaction.

2.2.1.2 Seeding strategy

Most likely, urban areas are going to be the high-density focus for vehicular networks, both with a high Wi-Fi and cellular coverage. Therefore, it is interesting to determine how to make the best usage of the full potential of leveraging V2V, by creating an initial set of nodes. The seeding strategy refers to the means of disseminating data by selecting a specific number of seeders. Though, in Mezghani et al. (2016) perspective, the vehicular environment is highly dynamic, making hard the forecasting of the typology of the mesh, while it is time-critical before it becomes entirely obsolete.

The most relevant recent study on how to select a seeder vehicle was performed by Kershaw and Krishnamachari (2015) in 2015. The authors studied the way to determine the set of nodes that would act as seeders in a vehicular network, where parameters such as proximity, encounters, and speed were considered. In this study, they performed on field tests determining the best strategy to disseminate the information, creating an epidemic propagation. The outcome of the authors' research are extremely important due to the lack of information currently available regarding types of seeding strategies.

Epidemic Propagation The behaviour of selecting one node to disseminate information is described as epidemic routing, leading to an epidemic propagation (Kershaw and Krishnamachari, 2015). Just like an epidemic that diffuses a manifestation of an infectious disease in a community at a certain time, a V2V content distribution network diffuses a seed to a vehicular network at a certain period.

As Gonçalves (2017) describes, the control theory and epidemiological models are intrinsically connected and its broad application can impact diverse subjects, such as software virus or marketing campaigns. In this particular case, epidemic routing is related to the dissemination of information. As an epidemic can propagate in different ways, through mathematical models (SIR - susceptible, infected and recovered/removed; SIS or SIRS model), the vehicular seeding can be defined differently depending on the strategy chosen. A parallelism can be made between the epidemic mathematical models and seeding strategies - susceptible is the most probable vehicle to be selected as seeder; infected is the actual seeder and recovered/removed - if the seeder already disseminated the information to its neighbours. Therefore, Kershaw and Krishnamachari (2015) compile the seeding strategy into four different categories: geographic proximity, speed, encounter graph, and hybrid.

Geographic proximity

- Random Selection: strategy with the minimum acceptable performance;
- Most Neighbours: strategy most likely to pick the surrounding neighbors;
- Equal Sized Geographic Partitions: distributing the seeds in a distant way so that one seed is less likely to overlap with another seed's satisfied nodes where the region is divided into equal slots and seeds are equally divided into these regions.

- Neighbour Elimination: Selecting a seed close to another seed is redundant due to the share of the same file in the same location. The seeds that are close to each other are eliminated from consideration.
- Loner Elimination: Selecting a seed in a long distance from the other overall nodes is not a potential good seeder as it can be considered an outlier. Hence, the nodes with less than a specific number of neighbors in a specific distance are removed from consideration.

Speed

- Speed Range Selection: The authors defend that the faster a node is moving, the faster it encounters other nodes and will be more spread out than a slowing pace. On one hand, congested areas are good for file dissemination within a certain distance. Though, not moving can also mean a restriction on further dissemination. Therefore, nodes whose average speed is in the range of minimum and maximum speed are selected as nodes.

Encounter graph

- Encounter Probability Elimination: This strategy takes into consideration the past vehicle meetings, forecasting that vehicles that already encountered themselves are most likely to encounter again.
- Highest Degree Selection: this strategy selects the nodes who have the most incident edges in the encounter graph, encountering the highest number of distinct nodes.

Hybrid strategy

- Neighbor and Loner Elimination: By utilising both neighbor and loner strategies, one is maximizing the potential of dissemination. Firstly, with the neighbor elimination, if seeds number increases, the pool becomes increasingly saturated, because near other nodes are eliminated. Secondly, with the loner elimination, the mesh becomes saturated with neighbors of existing seeds, because the far nodes are eliminated.
- Neighbor and Loner Elimination with Speed Range: This strategy selects seeds with a minimum number of neighbors moving in a similar speed range and then eliminates the neighbors.

In Figure **2.3** the authors conclude that the best strategy performers depended on the nseeder given. For 10 seeders the best performer depends on the time used. For 50 seeders, the chosen strategy is “Neighbor and Loner Elimination with Speed Range”. For 100 seeders, “Neighbor and Loner Elimination” has a better performance.

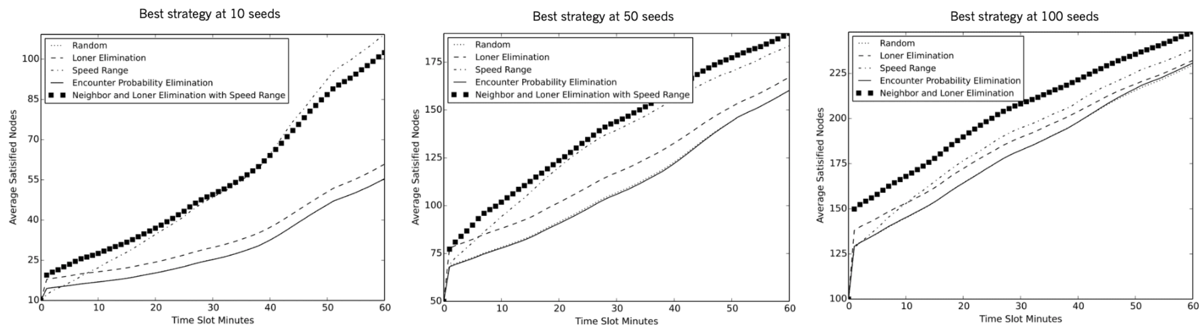


Figure 2.3: Best dissemination strategies with 10, 50 and 100 seeders (Kershaw and Krishnamachari, 2015)

As a conclusion from the study to apply in the current thesis research, the speed based strategies show the best performance, when the number of seeders are low and with long time experiments, whereas when the concentration of seeds is high, the best performance is obtained by deploying speed based strategies and eliminating nodes that are too far from other nodes or too near from other seeders.

Besides this, Mezghani et al. (2016) propose a scheme for the best seeding strategy, the Seed Selection scheme for maximally satisfying commuters interests in vehicular network (SIEVE). As a matter of fact, Mezghani et al. (2016) developed an algorithm to determine the selection of seeders using SIEVE, which is represented in Figure **2.4**, highly focused on the users' satisfaction in the content received. With that, the authors aim to maximize the utility for all vehicular users.

With this algorithm, the authors propose to propagate the content gradually by V2V opportunistic communications, where the selection scheme takes into consideration the users' interest and near-future contacts prediction. SIEVE demonstrates to have a better content utility against the other models developed in the area, including the above-mentioned one due to the fact they do not consider users' satisfaction.

SIEVE is structured down into four phases: the vehicle information gathering, the prediction of nodes impacted by the seed, the content utility computation, and seed selection, and the content object download and dissemination.

The algorithm is performed when a new content object is created and available to be disseminated for the different nodes (line 1). In line 2, the predicted time slots are forecasted. From line 3 to 15, it is described the impact of nodes of each vehicle during the defined time frame. In line 16, by knowing the impacted nodes, it is computed the content utility for each vehicle. Lines 18-19 define and select the node that has the highest content utility value as a seed for the content object.

All in all, Mezghani et al. (2016) proposes to include a new metric to non-safety applications V2V content dissemination: the users' interest.

A new content object o_j is created at event Time: T_e
$N \leftarrow$ number of prediction' time slots
for v_i IN $\mathcal{V}$ **do**
    Determine $D(v_i)$ direct neighbors of v_i
    ▷ *direct neighbors* $D(v_i)$ *correspond to* $[T_e, T_e + \delta t]$
    $\mathcal{L}_{v_i} \leftarrow \{v_i, D(v_i)\}$
    $n \leftarrow 1$
    while $n < N$ **do**
        $P \leftarrow [T_e + n \times \delta t, T_e + (n+1) \times \delta t]$
        $List_{copy} \leftarrow \mathcal{L}_{v_i}$
        for v_k IN $List_{copy}$ **do**
            Predict $FC(v_k, P)$ ▷ *future contacts of* v_k *during the period of time 'P'*
            $\mathcal{L}_{v_i} \leftarrow \mathcal{L}_{v_i} \cup FC(v_k, P)$
        end for
        $n \leftarrow n + 1$
    end while
    ▷$\mathcal{L}_{v_i}$ *contains the list of impacted nodes by* v_i *during the period of time* $[T_e, T_e + N \times \delta t]$
    Content_utility$(v_i, o_j) \leftarrow \sum_{k \in \mathcal{L}_{v_i}} I_{k,j}$
end for
$seed_{o_j} \leftarrow \max_{v_i} Content\_utility(v_i, o_j)$
return $seed_{o_j}$ ▷ is selected as seed for o_j

Figure 2.4: Seed selection using SIEVE (Mezghani et al., 2016)

2.2.1.3 Chunking

The chunking refers to means of dividing the file into different parts, the chunks. According to Recharte et al. (2019), the chunk size and decision algorithm for the content distribution OTA has a big impact on the performance of the protocol. It is not yet proved that if a greater higher density of vehicles facilitates the dissemination or if this cooperative dissemination model will run into congestion problems. For instance, a common cause for vehicles to reject a file was the fact of them being busy sending or receiving another chunk due to its high size.

In line with Darwin et al. (2014) there are two main chunking strategies: the Random Short Strategy (RSS) and Network Coding (NC).

To exchange data between vehicles, there is the need to split it in chunks of a constant size, with each chunk sent in a single parcel. When discussing chunks size, it should be considered that large files are affected by the intermittency of the V2V connections, while shorter parts are more easily sent. In that case, if an OBU fails to download one complete chunk from the current RSU, then the chunk must wait for the next RSU. There's where V2V plays a competitive advantage role, by allowing cars not to wait for the next RSU, but to exchange chunks among the vehicular environment. To do this exchange, each OBU should use a different approach. To exchange chunks with V2V, vehicles need to send a bitmap of their missing chunks.

The RSS makes the server send the file in a permutation random way, while the NC Strategy describes a linear combination with the original chunk and the one that is sent. Using RSS it was determined that the number of chunks is well approximated by a normal distribution. The mean and standard deviation do depend on the file size.

As a conclusion, in NC Strategy, the distribution of the different received chunks is independent of the file size. Then, NC proves to be a better strategy since RSS depends on the file size.

Thus, to enable all these vehicular communications, certain technologies are used such as DSRC, C-V2X and Internet Connectivity such as Wi-Fi and cellular broadband network technologies. The technologies for Vehicle Connectivity are further approached in the next section.

2.3 Technology for vehicle connectivity

In this section, there will be explored the technologies for vehicular communications focused on internet connectivity such as Wi-Fi and Cell technologies and inter-vehicle based communications such as DSRC and C-V2X. In the end, an overview of all technologies is made as well as the identification of the ones that currently support V2V communications.

Ad hoc wireless networks are a set of two or more gadgets that are outfitted with wireless communications and networking capacity that can communicate with each other either if in the same radio range or through intermediary nodes whenever it is necessary, accordingly to Toh (2001). The author also mentions the concept of Car-to-Car mobile communications, which was the basis for the creation of VANETs. In VANETs the information is trusted among vehicles, that create a network around them, each one of them contributing as a node, expanding the reach of the mesh. Moreover, Toh (2001) reported that V2V communications as the vehicular communications, transmitted relevant information to the surroundings, firstly with the purpose of dissemination of safety messages.

VANETs can use both wireless networking technologies, such as Wireless Local Access Networks (WLAN) or cellular technologies, being the short-range radio technologies the most prominent ones according to Sommer and Dressler (2014).

2.3.1 Wi-Fi

Wi-Fi technology, a WLAN standard, is the wireless communication based on the Institute of Electrical and Electronics Engineerings (IEEE) standard 802.11, trademarked by Wi-Fi Alliance which mission is to connect the world by driving the adoption and evolution of Wi-Fi globally (Wi-Fi Alliance, 2020). Thus, the origin of WLAN is the local area networks, where computers were part of a wired network in a fixed location (Dhanalakshmi and Sathiya, 2015). The first widely adopted WLAN standards were the 802.11a and 802.11b, published in 1999 by IEEE with higher speeds compared to the previous slow bit rate of these standards. These Wi-Fi standards operate in the frequency of 2.4GHz and 5GHz, the frequency that can vary from location to location, having the disadvantage of the bandwidth interference with other technologies such as Bluetooth gadgets and microwaves, since their channels are 20 MHz wide at 5GHz.

From the first generation, already six new ones were developed, being the latest and current one the Wi-Fi 6, based on the IEEE 802.11ax standard, which was introduced in September 2019. According to Wireless Broadband Alliance (2017b), Wi-Fi is the most used wireless communication technology, with 60% of mobile data traffic flows. The average download and upload speed for Wi-Fi is 74.32 MB/s and 40.83 MB/s, respectively. If compared with cellular broadband technologies, the download and upload speeds are weaker performing with a 31.95MB/s and 11.32 MB/s, respectively (Speed Test, 2020).

For WLAN networks, there are different authentication methods, such as Wi-Fi Protected Access (WPA), using Pre Shared Keys (PSK), Extensible Authentication Protocol (EAP) and Wireless Internet Service Provider roaming (WISPr). WPA is the most used, EAP uses central authentication servers and WISPr is used to provide access to the user in a way similar to cellular networks, where users have to log in in a captive portal to access the network (Marques et al., 2019).

In an automotive view, under Mourad et al. (2016) perspective, WLAN potential in the automotive industry is yet to be discovered (as far as 2016) due to the limitation of the number of devices in this domain, compared with other domains. Mainly premium sector has developed WLAN connectivity, which provides Internet connectivity for the passengers in the car as an access point.

Though, as stated by Xu et al. (2018a), offloading vehicular data traffic from cellular networks to roadside Wi-Fi networks has a high potential since it can not only alleviate the traffic congestion for cellular networks but also reduce the communication cost for vehicle users. Xu et al. (2018a) analyzed the effect of V2V assisted Wi-Fi offload, where the neighbor vehicles that connect to different APs can use their unproductive Wi-Fi resources to offload part of the peer's data traffic.

Since it is expected an increment in vehicular data traffic, spreading all the data through cellular will not only be expensive but also will create a network bottleneck for users. Therefore, maximizing the utility of Wi-Fi will have a positive impact on users' costs. On one hand, Wi-Fi is available around the world, achieving high link rates. Moreover, it is cost-effective to use Wi-Fi networks as both the Commercial-Off-The-Shelf (COTS) products and the Wi-Fi hotspot deployment are inexpensive (Xu et al., 2018a).

Even though in mobile devices the Wi-Fi interfaces are already built-in in the motherboard, in vehicles the OBU have Wi-fi antennas, preferably positioned outside the car to increase the range and avoid obstacles.

According to Akbilek et al. (2018), the latest generation of Wi-Fi, protocol IEEE 802.11ax is deeply attractive for in-vehicle activity due to the higher demand for throughputs and the low-cost data pipelines. Hence, the widespread deployment of urban-scale hotspot networks represents a highly valuable infrastructure already installed, capable of connecting not only user devices, but also vehicles. The potential of hotspots is still not fully used but can be beneficial when discussing vehicle connectivity.

Lu et al. (2014) defend the connection time by a Wi-Fi APs is affected by the movement of the user at different speeds. Movement makes the connection to an APs harder mainly for short connections, due to a long time wasted with the authentication, authorisation, and configuration of the Internet Protocol (IP). Though, these networks were designed, so far, for non-vehicular environments, since mobility affects negatively its performance, mainly for the signal loss due to channel fading and shadowing and anomalies in radio propagation channels.

Lu et al. (2014) also supports that for a better QoS, the connection time for Wi-Fi needs to be reduced, suggesting that V2V multi-hop increase ranges, improvements on the protocols for high mobility cases and further development of the infrastructure network of Wi-Fi hotspots.

2.3.2 DSRC

Mostly used for high data transmission crucial for safety purposes between two devices, DSRC is a short to medium range communication that takes 75 MHz of spectrum around the 5.9 GHz band (5.850-5.925 GHz), which was established by the United States Federal Communications Commission (FCC) in 1999 (Zeadally et al., 2012). Even though it was founded in the USA, this coverage varies depending on the different world regions. Being an extension of IEEE 802.11a created by the American Society for Testing and Materials, outlined for vehicles traveling at high speeds, DSRC was built to support V2V and V2R communications (Zeadally et al., 2012), using different channels out of the 7 that DSRC takes as it follows on Figure **2.5**.

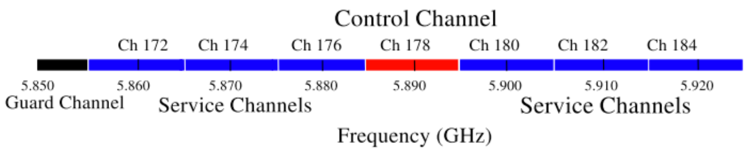


Figure 2.5: DSRC spectrum map (Naik et al., 2017)

One channel is solely focused on safety communications together with the other two that are maintained for special purposes, such as emergencies of critical public safety, with Basic Safety

Messages (BSM) containing vehicle position, velocity, and acceleration (Naik et al., 2017). Taking into account that while using DSRC the priority is given to safety applications Zeadally et al. (2012), the other channels can be either used as safety as well as non-safety applications such as digital maps and automatic tool collection. Naik et al. (2017) DSRC is then capable of fulfilling the requirements of extremely short latency for road communication. Though, according to Naik et al. (2017), FCC is considering broaden the band range to operate additionally in 5350-5470 MHz.

From the adaptation of IEEE 802.11a protocol, IEEE understood some limitations and created the Wireless Acess in Vehicular Environments (WAVE). Hence, physical and data connections of WAVE are made through 802.11p protocol. WAVE requires two devices: the RSU, the stationery device, and the OBU integrated into the vehicle. DSRC and WAVE can still function only with OBU for V2V communication (Zeadally et al., 2012).

More focused on the transport and network levels, the used standards are IEEE 1609. IEEE 1609.1 corresponds to management activities, IEEE 1609.2 to security, IEEE 1609.3 to define the network protocol, IEEE 1609.4 to support upper media control.

According to Krasniqi and Hajrizi (2016), there is a potential in this technology to be expanded to ITS, like driver-assisted vehicles and autonomous driving features. The author suggests DSRC and 5G can be competition, while in the fact they work as symbiotic technology, both coexisting at the same time. In another perspective, Naik et al. (2017) provided an interesting analysis between DSRC and Wi-Fi coexistence. From the author's point of view under the IEEE 802.11ac standard, mostly in the high bandwidth, certain channelization opportunities cannot be used by Wi-Fi means without causing interference to the DSRC connections.

Some countries already deploy DSRC for high-priority scenarios such as Japan and Australia, but it is expected to have more since automotive OEMs devoted to having 802.11p protocol in deployments from 2019 (Zeadally et al., 2019).

2.3.3 Broadband cellular network technologies

Communications that are carried onto the user wirelessly from mobile phone towers to digital portable devices are named broadband cellular technologies. This type of communication evolves each decade and is updated and standardized by the Third Generation Partnership Project (3GPP), from the beginning first generation, introduced in the 1980s, to the latest 5G standard. From one generation to the other, there are added releases that are built up on top of each other. The first generation had the purpose to facilitate voice communications only, based on analog systems. Then, with 2G additionally to the voice, text messages were introduced. Further, 3G started to enable internet access, video calling, and other entertainment applications. With 4G, considered also the LTE, increased mobile broadband, bringing voice over Internet Protocols, allowing the stream for video and gaming applications. 4G was deployed in 2009 and by 2019 it presented an 80% coverage across 87 countries (Boyland, 2019).

4G in vehicular environments has particular interest regarding the specifications met to satisfy use cases related to infotainment, especially because of the high data rates and low latency, used in an extensive coverage area (Araniti et al., 2013). Though, as a con, the LTE, as it is a cellular communication type, must go first through an infrastructure, wasting time and efficiency for traffic and safety applications, making that an expensive process. For that, V2V is more convenient. 4G presents latencies in the radio access up to 100 ms, using Orthogonal Frequency-Division Multiple Access (OFDMA) for downlink connection with up to 9.4MB/s and Single Carrier Frequency Division Multiple Access (SC-FDMA) for the uplink with up to 37.5 MB/s. Though, when in a high-density environment with several number of vehicles, latency can be too high for critical safety applications.

2.3.3.1 5G

5G is considered the next generation of cellular communication technology, still considered in the phase of development (release 16), with South Korea taking the lead in October 2019. Even though releases from 3GPP were done for 5G, low are the phone models equipped that support 5G. The main upgrade from 4G to 5G is the purpose it has to connect societies seamlessly, including cities, transportation systems, and user devices.

Krasniqi and Hajrizi (2016) defends that 5G will be a competitor of DSRC when it concerns low latency matters. Mostly, 5G brings a competitive advantage when it comes to the diversity of applications, not solely focused on safety. It can be used for V2V communication, infotainment (instead of 4G), radio modules and spectrum, (instead of Wi-Fi and Bluetooth) and updating directly the faults to OEMs. The biggest advantage of 5G is that it can cross over infrastructure, while DSRC can't, requiring new RSU and additional infrastructure.

According to the European Comission (2018), during the year of 2020, 5G connectivity infrastructure is foreseen to be an important (if not the major) type of communications for connected and automated mobility, allowing the development of digital ecosystems around AV, with International Mobile Telecommunications (IMT) setting the rate for 2.5 GB/s for downlink and 1.25GB/s for uplink, and user experience rates for 12.5MB/s and 6.25MB/s respectively. According to Wireless Broadband Alliance

(2017a) the use cases in movement allow the speed of 500km/h and the designated bandwidth reserved to be at least 100MHz above the 6GHz frequency band.

Albeit for major authors 5G is believed to have a positive impact on auto OEMs, which could avoid market and technical fragmentation, considered a trend and solution for most connectivity problems, Filippi et al. (2016) disagrees, defending that it will not be soon that technology communications as 5G will fully support the (safety or non-safety) V2X use cases. To support their statement, the authors assure that tested solutions based on the 802.11p protocol are ready right now and can be deployed on a large scale, anywhere, anytime. All in all, the author believes the future we are prospecting can be already happening today if using the benefits of 802.11p. Despite believing that it is wiser to invest in V2X applications enabled by 802.11p, the coexistence of both communication types have been studied.

To reinforce Filippi et al. (2016) statement, accordingly to Boban et al. (2018) cellular technologies have not been designed to satisfy low latency values and high-reliability requirements.

Notwithstanding, 5G besides being the fastest generation so far, requires a high prepared infrastructure, resulting in higher costs and therefore higher prices per GB compared with previous generations.

As seen, there is no consensus regarding 5G, mainly because it's yet not fully defined, but rather still work in progress. Not much equipment has been developed neither installed to be ready for the new automotive era. Nevertheless, 5G Automotive Association (5GAA) has been focusing on the development of 5G V2X linked to the automotive industry, to ensure the fulfillment of the vehicular use cases, prospecting a promising performance. Yet, none of these parameters were tested so far at a full scale, remaining unknown if 5G will effectively make a positive change in vehicular environments.

Since the thesis development is focused on V2V communications mostly through Wi-Fi, cellular is not much considered. Though, when mentioning it, only 4G and 5G will be considered. 3GPP has already included in their releases the concept of C-V2X, which oversees the usage of both 4G and 5G technologies.

2.3.4 C-V2X

The cellular-vehicle-to-everything (C-V2X) is a 3GPP standard, launched in 2016, that specifies the technology to achieve the V2X requirements for V2V and V2I, using both 4G/LTE and 5G , using the original framework. This V2X standard was included in release 14, motivated by the growing needs of data in the automotive industry, whose C-V2X deployments have been giving a lot of relevance lately. Then, in release 15, 3GPP broadened this definition to support the 5G based use cases, while in release 16 the scope is expanded to include 5G direct communications for V2V and V2I (GSA, 2019).

Cellular V2X describes the usual cellular uplink/downlink transmission, where the equipped vehicle communicates with a base station to reach either an edge server, back-end server or connect to another vehicle. For that, besides the macrocells, it also includes small cells in the form of RSU, which will not only improve coverage but also strengthen the overall cell throughput, enabling them to have improved functionalities, such as fast radio access, handover among RSU and regulated resource allocation, decreasing the latency (Boban et al., 2018).

The initiative defines two types of communication modes: Device- to- device: direct communication between two devices without an installed network infrastructure; Device-to-cell: Uses an operator-managed infrastructure to enable network resources to provide V2I communications, enabling interaction with cloud services using the traditional cellular infrastructure (Zeadally et al., 2019).

So far, C-V2X is still in the testing phase, whose ecosystem has 25 active telecommunication operators from 16 countries participating in tests that are the effort across the entire industry, from governments and policy-makers to OEMs and tier-1 suppliers (GSA, 2019). Nevertheless, the usability of C-V2X goes beyond safety and traffic management cases and includes scenarios as enabling the development of autonomous vehicles, aftermarket, and new infotainment services (GSA, 2019).

According to Vukadinovic et al. (2018), 3GPP's specifications include short-range V2V communications, using an air interface used for direct communications amongst vehicles. C-V2X will continue to develop in future 3GPP standard releases, with a clear roadmap to 5G based C-V2X, complementing the LTE based C-V2X, providing ultra-high reliability and ultra-low latency performance. Adding to that, 5G V2X will support communication via three different paradigms: cellular V2X, cellular-assisted V2V and cellular non-assisted V2V (Boban et al., 2018).

Even though C-V2X seems promising, there are some limitations such as the frequency band allocated to this technology. 5GAA requested to use the 5.9GHz band to allow C-V2X deployments, however, FCC (2019) is considering to allocate the previous DSRC frequency band to C-V2X.

Albeit C-V2X is still under development, a relevant discussion has been brought up, dividing key stakeholders. Though it's hard to distinguish the relevance of C-V2X compared to other technologies, since it has been analysed majorly by great defensors of C-V2X such as 3GPP, 5GAA, and NXP, leading to a biased conclusion from the existent literature. Nevertheless, the market should keep a close analysis in the future applications of C-V2X.

To conclude, in accordance with Zeadally et al. (2019), being V2V a low latency, high reliability, and guaranteed data rate technology, it needs a proper communication protocol to assure the QoS. The US National Highway Traffic Safety Administration (NHTSA) endorses the usage of DSRC as the standard for

V2V technologies. Howbeit, alternative technologies are considered. For instance, wireless communications between the OBU and RSU use WAVE Short Message Protocol (WSMP), allow the interchange of messages in a low latency environment. Currently, Wi-Fi 6 and 5G present the most attractive bit rates and end-to-end latencies.

2.4 Reflection upon literature review findings

The V2V communication technology is at a stage of consolidation and incorporation of practical points to implement in the development of the thesis. At this point, the benefits of contributing to the development of non-safety applications with V2V technology are well established, providing strategies on how to disseminate this type of content, even though most of the state-of-the-art referred to this communication as a safety purposes development. Hence, the expansion of the applications that V2V yields are in a broader spectrum, yet not fully discovered.

Despite the good existing information regarding the topic, the costly and market impact for automotive OEMs has not been profoundly investigated. Yet, as a major result of the master thesis, with the background analyzed in the state of the art, a consolidated solution will be tested, experimenting either if the value proposition of V2V for non-safety applications is prompt to development or to nullify its application with an Wi-Fi based solution.

In this literature review, it was introduced the need and purpose of the master thesis: the research and development needed in IoT, a topic that comprises mostly all the future reality. With IoT topics such as Smart Cities and Connected Cars gaining most of the relevance, the connection of both brings the pertinence of the research in V2X connectivity to enhance the better performance of future cities, mainly regarding future mobility.

Consequently, vehicles are expected to connect to everything: to the cloud, to the device, to the grid, to the infrastructure, to pedestrians, to the roadside and vehicles. With the literature analysed, one can infer that most of the connections were developed having a strong emphasis on safety, preventing human error, and reducing injuries and deaths. Nevertheless, with more recent research, it is possible to presume that the trend is, besides keeping developing the safety applications, to focus as well on the non-safety services. Meaning that, as the in-vehicle experience is changing over the years, the QoS and the user experience have to raise the standards and improve its development. Applications such as software updates over the air, as well as instant map updates/ warnings and infotainment refinement will be a sooner reality. With this development, a higher concern arises: as the data generation increases, the awareness on the security of the data rises, which will request a large investment mostly from the government's side, contributing to regulations and infrastructure. Communication among vehicles, for example if sending a file from one vehicle to another, happens with different seeding (how to disseminate the information amongst a mesh network) and chunking strategies (how to divide the files in chunks), resembling an epidemic propagation.

In the seeding research, the SIEVE algorithm was the main highlight researched. Moreover, the study developed by Kershaw and Krishnamachari (2015) suggested some testing hypotheses that will be considered in the tests, depending on location proximity, speed, encounter times, and also a mixture of both strategies. For this type of communication to happen there is the need of having technologies that enable them. Hence, the state-of-the-art for technologies for vehicle connectivity was also performed, exploring Wi-Fi, Cell, DSRC, and C-V2X. The major outcome is that due to the high expenditure with cell, Wi-Fi is preferred to be used in V2V. Also, DSRC was beforehand applied in V2V communications, but more related with safety warnings for the passenger. C-V2X is expected to take a DSRC role, even though there is not yet enough infrastructure to support the technology. All in all, V2V looked in a non-safety perspective brings a lot of yet unknown potential for automotive OEMs that will be soon key factors.

Thus, the main contribution expected from the thesis is the possibility of enhancing the current literature with a practical example in a high-density vehicular zone while developing a solution for Veniam and understand its feasibility.

Chapter 3

Case description and critical analysis

The state-of-the-art analysed provided academic background on the V2V technological topic. In this chapter, an industry-focused analysis and research will be performed, aiming to provide an overview of the case and identify either if there exists or not a market fit for V2V non-safety applications. With the following issue tree in Figure **3.1**, there were underlined the pillars to determine industrially the statement stated above.

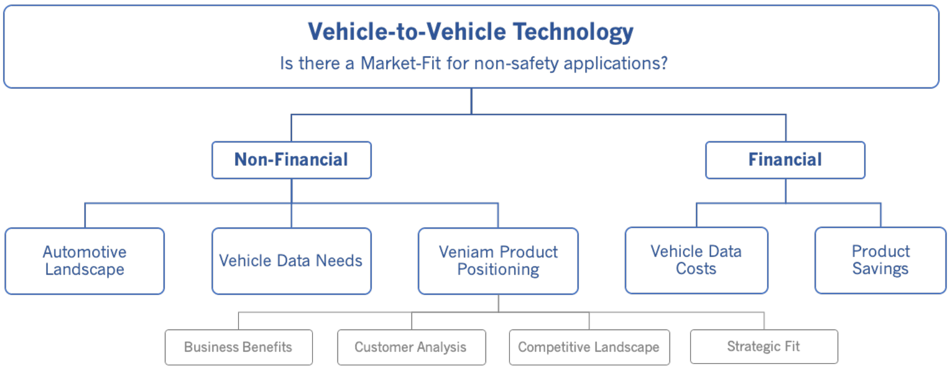


Figure 3.1: Issue tree to map V2V readiness

In the non-financial topics, the starting point embraces and overview of the automotive landscape where current trends are identified as well as the processes involved to get an automotive software ready for production, identifying the main differences between mass and premium OEMs. Furthermore, the vehicle data needs are explored, taking into consideration the data volume per consumption in different scenarios such as moving or stationary, delay-tolerant or high priority, car specific or fleet data. As a result, Veniam's product positioning is performed with a focus on strategic and business benefits alongside customer analysis, and competitive landscape.

In the financial issues, the data costs are studied as well as the likely savings earned by the OEMs. All issues considered, the current chapter addresses a market analysis business case following the trends of connected vehicles, with an overview of applications enabled by the technology. All in all, the readiness to deploy Veniam's software is fully refined.

3.1 Automotive Landscape

In this section, it is described a historical vehicle evolution review, an evaluation of the current state of CASE vehicles, the condition of the supply chain in the context of software integration, as well as the main challenges faced by this industry.

3.1.1 Automotive Evolution

The automotive industry has been shifting paradigms from decade to decade. Recalling the starting point of mobility, in 1700, the first vehicles were moved by steam engines. Later, it was developed a gas-powered vehicle solution created by Karl Benz, back in 1885, in a car moved by three wheels where two people could sit, serving as inspiration for other automakers to build similar machines. Thus, the creation of gas-powered vehicles by Benz was a turning point for automotive development.

Subsequently, in 1906, Henry Ford developed the Model T, an affordable model that recalls today's automotive design. Ford became a reference not only in an automotive corporation, but also as an industrial influencer in what concerns production assembly lines for mass production and lean manufacturing.

From 1940 to 1970, major developments regarding safety were created: power steering, cruise control, three-point seat belts, and airbag integration. At the beginning of 1990, electronics gained relevance especially in developing key-less entry systems, electric doors and windows, sunroofs, and CD players. With the beginning of the current century, cars were integrating music players, hard drives, advanced safety systems, GPS, and automatic parking (Drive Safely, 2020).

As seen, the automotive industry constantly adapts to new technological trends and customers' needs. Occasionally, it is the actual automotive industry that grasps technological innovation and causes a market shift, not only in the automotive range but with impacts in various businesses and economies.

Nowadays, and as mentioned in the previous chapter, one of the main topics regarding IoT development is focused on connected cars. Furthermore, the industry is not only overseeing solely Connected vehicles, but also Autonomous, Shared, and Electric vehicles, collectively named as CASE. Briefly, CASE represents an eco-friendly, efficient, convenient, safer, and complacent solution for the automotive OEMs, which will be further explained.

3.1.1.1 Connected Vehicles (CV)

The denomination of connected vehicles invokes the applications and services that associate the car with its ecosystem. Therefore, connectivity is the feature that bonds the rest of the mentioned CASE innovations, whose vehicles include hardware that capacitates the software, more specifically wireless communications within and outside the car. In fact, connectivity is the key enabler for the genesis of ITS.

There are three main parties involved in connectivity: technology industry, customers, and governments. The first, the technology, is the facilitator of the other features such as electric and autonomous vehicles, which is now facing a vociferous digital transformation, whose success highly depends on the way software integration is performed. As PwC (2019) describes, future cars will be assembled with connectivity features, including internet access with a WLAN connection. For that reason, OEMs will need to refocus their processes onto product ideation and design, out-sourcing some technologies activities, while moving into Business to Consumer (B2C) services instead of doing this process through a dealer network (PwC, 2019). The second, the customers, expect shared and on-demand mobility. Lastly, the governments are doing an effort to develop legislation that is compatible with the growth of connected vehicles, such as reducing taxes and sustainable policies while managing the city ecosystem and infrastructures.

As a positive effect, connected cars will contribute to a decrease in the environmental impact of mobility while contributing to a increasing economic growth. Also, it promotes passengers' safety by taking advantage of ADAS while improving their Quality of Experience, more enriched due to the consistent connection. Likewise, for OEMs, connectivity brings a financial new perspective, contributing to the development of new revenue streams through digital services, that continue its income even after production with a fee per car and per passengers' usage for their services, that can be paid OTA, as Veniam business model indicates.

To that end, instead of being perceived as a premium feature, connectivity is being recognized as a guaranteed asset by most consumers. Thus, OEMs tend to prioritize this innovation, mostly since regulations require that vehicles need to be connected for safety purposes (PwC, 2019). As follows, cost-efficient connectivity is a major concern by the automotive industry, especially to the automakers.

Some of the main features of car connectivity for premium owners include vehicle communication with smart roads and traffic service, vehicle communication with other cars (to predict traffic for example), full integration with new and older phones (considered a necessity by consumers), full integration with "personal" assistants (such as Siri or Alexa), and full integration with media subscription services (such as Spotify) (McKinsey, 2019b). As a matter of fact, McKinsey (2019a) has defined a scale of five levels of connectivity, incrementally growing , which involve cumulative stages of features that augment the consumer experience, broadening the possibilities of a connected vehicle, from new revenue streams, to cost savings and passenger safety and security. In level 1 the driver is capable of tracking standard vehicle operations and oversee the generic hardware connectivity. In level 2 the driver can use the personal profile to enter digital services from external entities and platforms. In level 3, all of the occupants enjoy a personalised experience by their preferences in the mean of infotainment, target advertising, or controls. In level 4, the occupants interact with the vehicle and receive dynamic recommendations. Lastly, in level 5, artificial intelligence is capable of detecting each occupant's needs and satisfies them, by performing unprogrammed tasks.

As illustrated in Figure **3.2**, it is expected that by 2030, 45% of global new-car sales could be at level 3 or above in connectivity.

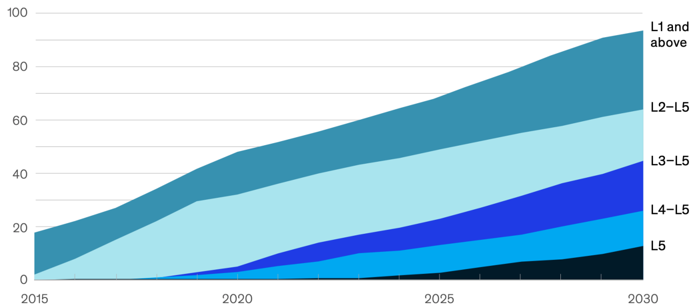


Figure 3.2: Expectation of connectivity vehicle level (%) by 2030 (McKinsey, 2019a)

In the PwC (2019) report, it is also envisioned that by 2030, China, USA, and EU alone will grow to be $ 81.000 million in the market of vehicle digital connected services. Furthermore, according to McKinsey (2019a) 40% of today's drivers would be ready to shift their brand's choice for the next acquisition for a better vehicular connectivity service.

For connectivity purposes, from safety to user experience, data must be shared within and among vehicles. Within the single vehicle, it requires the passengers' connectivity, entailing continuous connectivity to the Internet while on the move. Besides that, connectivity between vehicles, requires a well prepared ecosystem that includes vehicles, infrastructure, the cloud, and the Internet. This arises a new impact in what it concerns data sharing since it is different to share a file while moving at high speeds or if stationary. Therefore, new technologies are emerging and being under research from most of the OEMs.

3.1.1.2 Autonomous Vehicles (AV)

The autonomous vehicle, also known as the self-driving vehicle (SDV),is a way of transportation where the human driver is discharged by the independent vehicle's movement controlled by sensors that are capable of understanding the surrounding environment, moving harmlessly and enabling a better experience for the passengers. As stated in BCG (2017) the benefits of AV include improved road safety, decrease in pollution, increase in traffic and public transportation efficiencies, improve reliability and experience, and long-term cost savings.

For attesting the advancements in AVs capabilities and utilisation, the Society of Autonomy Engineers (SAE (2018)) developed a "Taxonomy and Definition for Terms Related to On-Road Motor Vehicle Automated Driving Systems". This guideline is composed of 6 levels of autonomy, from 0 to 5, from no automation to full vehicle autonomy, respectively. This scale should not be confused with the one explained previously on connected vehicles.

From level 0 to 2, the human is driving and must constantly supervise actions such as steering, braking, and accelerating as needed to maintain safety. In L0, the ADAS features are limited to providing warnings and momentary assistance. In L1, the ADAS features provide steering or brake/acceleration support to the driver. In L2, both use cases mentioned in L1 are provided. L3 is the turning point between the constant supervision of the driver and the automated driving features. In L3, the driver is not required to control the vehicle for some operational tasks, except only when the feature requests to do so. For both L4 and L5, the driver is not driving, even if it is seated in the "driver's seat". The difference is that in L4, the car will drive only when certain conditions are met, whereas in L5 it can drive everywhere in all conditions (SAE, 2018). There is a correlation when comparing the category of vehicle with the level of automation (the description of categories of OEMs can be found in subsection **3.1.2.2**). It is expected that Premium vehicles will achieve higher levels of automation when compared to mass market ones, as it can be seen in the following Table **3.1**, where "M" corresponds to "Mass Market", "P" to the "Premium Market" and "C" to "Concept". By 2030, it is expected that Premium category achieves L5.

Regardless of the latest developments in the automotive ecosystem, the current level of autonomy in the market is level 3 for premium OEMs. For instance, Tesla's Autopilot enables lane keeping, lane changing, distance keeping, and cruise control, which are in between level 2 and 3.

China is predicted to become the largest adopter of AVs, expecting to have 66% of the passenger-kilometer traveled by 2040 through autonomous technologies. It is estimated that it will engender a market revenue of $1.1 trillion for mobility services and $0.9 trillion from sales of AVs that year (McKinsey, 2019a).

In line with the same report from McKinsey (2019a), AVs are taking more time to go-to-market than expected. The main reason behind is that experts came to the realisation that the problem does not only involve the car architecture but also the cities and governments structuring for a controlled environment for AVs. Overall, the progress in AVs by 2019 was not as fast as previously forecasted, leading OEMs to have to revisit their automation plans for level 4 and 5 applications. As discussed, one of the limitations to AVs implementation have been the legal frameworks and regulations imposed by governments, since they vary depending on the region.

To achieve the reality of level 5, vehicles will need to train their Artificial Intelligence interfaces, with high relevance both on processing data and connectivity of the network to perform effective driving high precision decisions. Whilst innovative technologies emerge generating value, there is not a clear path of when and where the economic profit will start to progress.

Table 3.1: Autonomy level evolution by year and market type (PwC, 2019)

SAE Level	ADAS Features/ Use Cases	2020	2025	2030
L1	Adaptative cruise control	M	M	M
	Assistive parking (driver-assisted)	M	M	M
	Lane Keep assist (system steering)	M	M	M
	Blind-spot monitoring rear/side (system steering)	M	M	M
L2	Assistive parking (remote/key parking)	M	M	M
	Lane changing assist	P	M	M
L3	Emergency assistant	P	M	M
	Traffic jam assistant without lane change	P	M	M
	Highway autopilot (single-lane)	P	M	M
	Highway autopilot (including lane change)	P	M	M
	Intersection movement assist	P	M	M
L4	Fully autonomous valet parking	P	M	M
	Full highway pilot with lane change	C	M	M
	Urban autopilot	C	P	M
L5	Full autonomy	C	C	P
	People mover	C	C	C

3.1.1.3 Shared Vehicles (SV)

"Shared mobility" has become a popular term in the automotive landscape, which means the utilisation of a vehicle or other transportation mode as the user needs it. It is considered a transportation strategy that provides users access to transportation services as they need.

Shared mobility can be branched into two categories: the car-sharing and ride-hailing. In the first, users are still driving the vehicles that they have chosen whereas in the second, the users don't drive and mobility is provided as a service, the Mobility-as-a-Service model, MaaS.

The European MaaS market will be worth $451bn by 2030, compared with $25bn in 2017, but it will be clearly overtaken by China by 2030 (PwC, 2018).

Meanwhile, it is expected that it will slow global vehicle sales but not reverse them, since there will be fewer vehicles on the road due to the sharing component. Nonetheless, at least for the next 15 years in developing countries, vehicle sales will surpass the shared mobility impact (McKinsey, 2017). Also, sharing vehicles increases the vehicle utilisation and therefore drives costs down significantly (BCG, 2017), as well as reducing urban congestion and emissions.

As mentioned by McKinsey (2017), as the trend of shared mobility gains relevance, the OEMs and their suppliers need to understand the why behind the popularity of this concept. Most likely, they will not be able to benefit from the shared mobility ultimate success.

Nevertheless, when asked to a today user of car-sharing and ride-hailing how the usage will evolve in the following years (as stated in Figure **3.3**), the large part of the respondents replied that will increase or increase a lot.

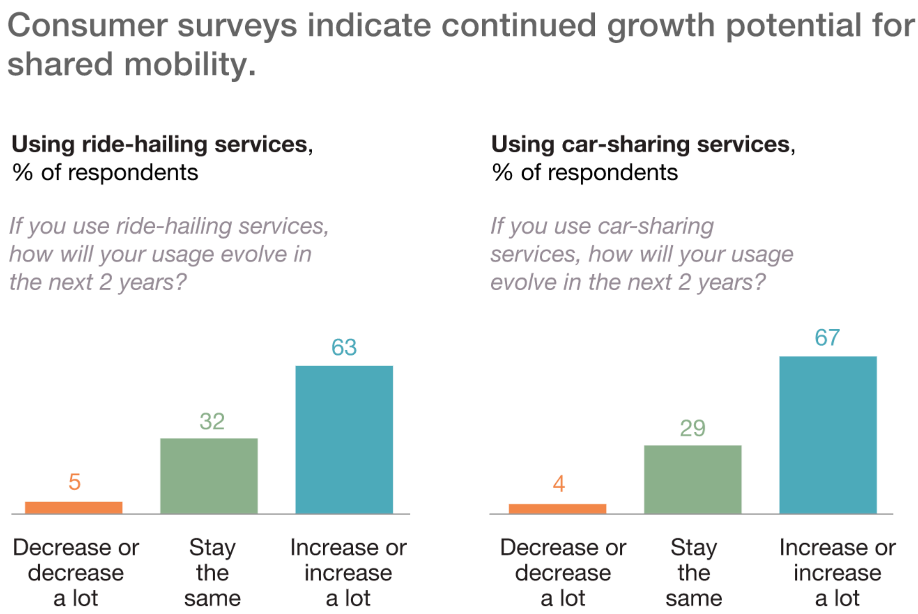


Figure 3.3: McKinsey's 2017 consumer survey indicates shared mobility should see further growth (McKinsey, 2017)

Adding to that, the practice shift in mobility within big cities has changed, where combustion engines will be banned while regulations cease the private vehicle's access to the inner-city areas. Therefore, the expansion in shared mobility will largely depend on how the landscape of the automotive industry tackles the user pain points and solve governmental issues. For instance, if the transportation causes a high discomfort on the passenger due to the presence of passengers that are strangers or if the solo drive is highly expensive, then users will not be prompt to use effectively the shared mobility (McKinsey, 2017).

To conclude, incited by the connectivity in new cars, the Mobility-as-a-Service (MaaS) business model will in 10 years justify 22% of the automotive revenue, balancing the loss in individual vehicle sales.

3.1.1.4 Electric Vehicles (EV)

An Electric Vehicle (EV) is a vehicle that uses electric motors for propulsion, powered by a self-contained battery or electricity from external sources, or solar panels or an electric generator that switch fuel to electricity. The autonomy of the car depends directly on the capacity of the batteries, the power of the engine, and each user driving style. Also, the charging time depends on the storage capacity of the battery and the power that the EV is capable of receiving and the quantity of power present in the charging point (EDP - Energias de Portugal, 2020).

In the premium market segment, Tesla has recently announced the Cybertruck, which has awaken the second phase of growth for the EV evolution. In the mass market segment, Volkswagen announced intentions to commence a family of EVs priced below $22,000, targeting city inhabitants.

As stated in Figure **3.4**, the EVs sales will be boosted by legislation, especially in China(50%) and EU(44%) in 2030. Both in China and the EU there will be built sufficient public charging infrastructure by 2025 with strong legislative pushes by governments. However, in the U.S., mobility patterns are not expected to change as much as in China and the EU by 2030 (PwC, 2018).

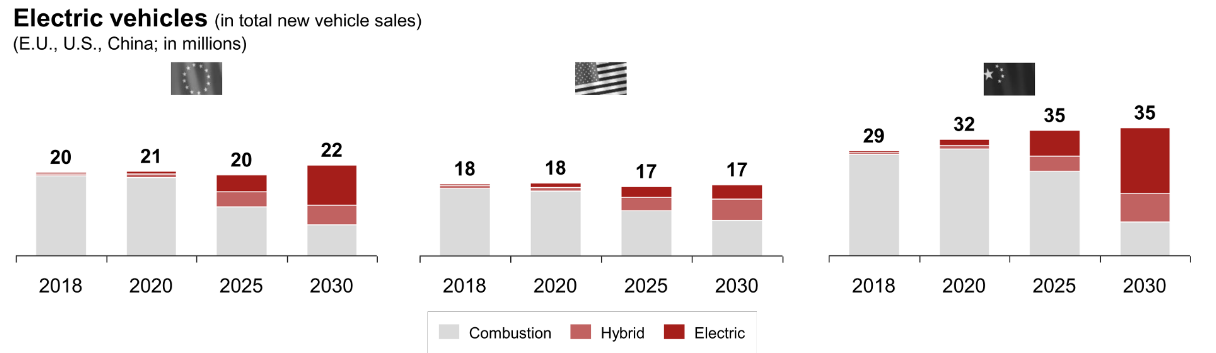


Figure 3.4: Electric vehicle sales growth (PwC, 2018)

Thus, electricity, as most analysts believe, will act as an intermediate for the transition to a MaaS model, predicting that in the future it will be more comfortable to use a service rather than having a stationary valuable asset (PwC, 2019), contributing to the vision of shared mobility as well.

Besides that, from the COVID-19 current situation which has impacted all mobility (where mobility was almost nonexistent), it is clear that internal combustion engine is causing a high level of pollution, which can easily be replaced by the Zero Emissions EVs (Forbes, 2020b), that provide a wealth societal benefit such as reduced gas emission (BCG, 2017) and tax benefits.

EDP - Energias de Portugal (2020) states that EV bring additional benefits when compared with regular vehicles:

- **Economic benefits:** Reduced energy cost per distance traveled (consuming 15 kWh per 100 km (around 2.5 € at an outlet), which is less than 50% of the comparable diesel and petrol cost.
- **Zero emissions:** The carbon footprint (carbon dioxide emissions) is zero.
- **Convenience:** The user can charge the vehicle where it is the most convenient place, from home to a city park to a charging point on a highway.
- **Financial incentives:** Governments are encouraging to purchase electric vehicles with measures such as parking fee discounts, benefits for companies with a reduction in Value Added Tax (VAT), exemption of vehicle, and single road taxes for particular users and monetary incentives for the purchase of electric vehicles.

Thus, the transition to electric mobility will affect the automotive ecosystem (from dealers to maintenance networks). Thus, with the higher interest from several parties in the ecosystem, automotive OEMs are shifting their approach to direct sales, speeding up the process, and making EVs a wise alternative for the society (Forbes, 2020b).

Overall, according to BCG (2017), CASE vehicles will reduce the cost per mile by as much as 50%. These saving come from different aspects such as:

- As the software cost is the same, if the utilization rises, then the cost per mile is lower;
- Insurance lower on cost per mile basis due to fewer accidents;
- CASE vehicles are powered by electricity, which is cheaper than fuel;
- CASE vehicles require lower maintenance on per mile basis, since they are always connected.

3.1.2 Supply Chain in the context of software integration on automotive industry

From a general point of view, the supply chain for the automotive industry is based on the following process: Raw materials (p.e.: steel and aluminum), Tier-2 and sub-tier suppliers (component suppliers), Tier-1 (module and sub-assembly and component suppliers), OEMs (brands such as Ford), dealer networks and end-customer.

In the context of software integration from an external service provider in the automotive industry, the focus in the supply chain is in the Tier-1 and OEMs. Directly, the end customer (the driver or passenger) do not enter the process, since most software services enterprises act on a B2B (Business to Business) basis and not on a B2C (Business to Consumer) level. Indirectly, the service provider needs to align their value proposition for the better interest of the OEMs, which is mainly focused on the satisfaction of the end customer. Therefore, the end-user is constantly mentioned from the service side, to satisfy the needs automotive OEMs has, but doesn't act as the main stakeholder in the process of software integration.

Therefore, in this context, software integration can be clustered into three downstream parts: the Tier-1, the OEMs, and the service provider that developed the software to be integrated.

According to Simon Kucher (2018), spending by OEMs and Tier-1 suppliers on software-related Research and Development is expected to increase a compound annual growth rate (CAGR) of 16.1 percent, from 37.9 billion euros in 2015 to 168.8 billion euros in 2025.

As stated by McKinsey (2020),OEMs, Tier-1 suppliers and tech service provider companies could create their own software platforms separately. Though, while OEMs don't have the capability, resources, and knowledge to act in all the fronts that involve vehicular innovation, tech companies do. On one hand, for OEMs building that business from the basis would be expensive, harsh, and time-consuming. On the other hand, tech companies are stronger in software development but lack hardware knowledge on how to deploy the solution in the OEMs. Regarding Tier-1s, they lack knowledge both in the software proficiency and hardware arrangement.

Thereupon, all the symbiotic dynamics (both technical and commercial) increase the overall knowledge by all parties and it's crucial for automotive development.

3.1.2.1 Tier-1

Tier-1s are categorized as companies that supply parts or systems directly to OEMs, developing smaller pieces that build up in a single-vehicle in the OEMs. These systems are mainly composed of automotive hardware that is pushed by OEMs due to their specific demand with exact parameters such as motion and temperature.

The Tier-1 concept emerges as a complement to reassure the OEMs needs. The car manufacturing needs different pieces to become usable, and while the OEMs can't satisfy all the development of the pieces, they tackle this resource shortcoming with Tier-1s. Adding to that, Tier-2 are the ones that sell components to Tier-1 factories. So, examples of Tier-1 suppliers for the automotive industry include ZF, Continental, Denso, Harman, and Bosch (Silver, 2016).

Albeit Tier-1s are independent organisations from OEMs, most of them are vehemently linked to certain OEMs. Normally, when in the context of software integration, Tier-1s are responsible for design the hardware, perform Operating System (OS) configurations, and implements their functions, establishing the connection with other components such as sensors (Symeonidis et al., 2015).

3.1.2.2 OEM

Following Tier-1s, come the Original Equipment Manufacturers, commonly named as automotive manufacturers. Although these producers are named “manufacturers”, in fact, their biggest focus is on design, market and assembling of the equipment for the final product. Even though OEMs produce some components, the gross part of the “equipment” comes from Tier-1s.

Regarding software, some OEMs develop it internally (the in-house development), while the others outsource this technical knowledge to other suppliers (Silver, 2016).

Hence, purchasing processes both to OEMs and suppliers are being shaped to these new realms, since nowadays software is the most important piece of a component - mostly being sold without the hardware, formerly considered the vital piece for the final product (Simon Kucher, 2018). Even though OEMs dispute market share, they no longer act alone, mostly when there is a prevailing interest from both sides. For instance, for end-to-end software platforms partners developed the core operating system but then each OEMs would have proprietorship on the code for each of their vehicles through well-built interfaces. Though, this OEMs-tech company relationship will not develop perfect results. From the OEMs side, there must exist an effort to continue learning to educate employees on strong software design principles. Also, there should exist an alignment between both parties regarding the communication type, requiring an agile development of frameworks and efficient governance systems (McKinsey, 2020).

In short, OEMs shifted their paradigm from car makers (from beginning to end) to tech companies that aggregate value from different parties, in order to solve mobility problems (Deloitte University Press, 2015).

Therefore, the development of tech innovations for the vision of Connected, Autonomous, Shareable, and Electric cars has been mostly made by tech companies, academics, and government programs and less by OEMs only (Krasniqi and Hajrizi, 2016).

Examples of automotive OEMs include General Motors (GM), Fiat Chrysler Automobiles (FCA), PSA (includes Peugeot, Citroën, DS, Opel, and Vauxhall brands), Ford, Honda and Volkswagen (VW).

Different OEMs can build different types of vehicles: the premium and the mass market.

Premium Market OEMs A premium vehicle aims to allow the driver and passengers to travel with higher comfort, a higher level of equipment, a higher level of connectivity and autonomy, and an increased perception of quality when compared to mass-market vehicles. Commonly, their components present high quality and pleasure senses while using the vehicle, from the initial design to the end detail of the manufacture process. These features together with the branding of the known OEMs translate into an increased price of the vehicle. Premium Market OEMs are considered luxurious brands such as Rolls Royce, Maserati, Porsche, BMW, Mercedes, among others. Though, as said previously, some OEMs can opt to produce both premium and mass-market vehicles to stand in both niches. For instance, albeit Ford is known for the mass market (with Ford Fiesta for example), Ford Lincoln is their premium brand.

Mass Market OEMs Mass market OEMs are the ones categorised for the affordability and comfort for daily tasks. It is considered to be produced in a large scale for a significant number of end-users, in order to decrease production costs and reduce the vending price. The automotive mass-market focuses on consumers with a high variety and not a specific type of background.

Even though this category can't reach the same levels of autonomy as the premium one, some mass-market OEMs are taking the lead. For instance, Volkswagen will be the first mass-market electric car profit maker (Forbes, 2020a), whereas Hyundai expects to roll out mass market electric vehicles in 3 years (Babu, 2020).

It is assured, as seen previously, that premium category enables a more connected and autonomous world, with more developed and top-notch features comparing to the mass market. Also, while premium OEMs take an active role in deploying the latest innovations, mass market OEMs rely more on commonality and cost-sharing models (McKinsey, 2020).

3.1.2.3 Software Integration

Software Integration is a long time process from the tech company and OEMs side, from the first contact to the production-ready deal. This integration stage is typically inserted in the phase before being ready for production.

The process starts with a Proof of Concept (POC), which is a demonstration of the feasibility of the product, to verify if the theoretical concept is supported by the practical potential. A demonstration is performed to the customer as shown in Appendix **A**. Then, the Integration and Business case is performed, where all the specifications and details are consolidated and deployed for analysis. Thirdly, the Non-Recurring Engineering (NRE) is a one-time cost for the OEMs, that refers to a cost to research, design, develop, and test the product performance. The NRE is the most financial-wise important step since it takes into consideration if the product is going to be profitable or not. Therefore, if NRE succeeds, most likely it proceeds to Production, the latest stage, where the deal is closed and the software deployed in the OEMs' vehicles.

Albeit the ideal stage for a tech company such as Veniam is to close contracts up to production, some projects can land in each of the four steps mentioned above. Therefore, for each of them a state is attributed: Statement of Work (SOW) (which consists of a first content alignment towards the software integration), Ongoing Project, and Project Completed.

3.1.2.4 Challenges and opportunities faced in the automotive ecosystem

The automotive ecosystem is currently living under a positive vision, which has been majorly impacted by a negative cause, calling into question the ability to develop a CASE world.

For the positive side, CASE is a market with several opportunities to entail. To start with, it is estimated that by 2030, 25% of the miles traveled in the US will be via CASE vehicles, meaning that there is plenty of open space do discover and deploy these technologies. Therefore, for this reality to happen, an impactful alteration has to be made when it regards the vehicle product life cycle and its development. With that, both OEMs and suppliers are forced to approach a more agile way of innovation and engineering, modifying their entire business models. Thus, with all of the switches, billions of dollars will still be invested in antiquated assets or job functions, calling for retraining or a repurposing of their positions (BCG, 2017). Also, the connectedness part of vehicles carries a big concern in security matters, leaving a lot of opportunities to research and develop new frameworks: as technology rises within the car, more can be the frauds committed by hackers, leading to an unwanted control of the vehicle (they could force them to brake, accelerate or steer).

All in all, these are the main challenges and opportunities faced by both OEMs, suppliers, and tech companies. Adding to these, the tech startups have been seeing a decrease in seed funding, but an increase in the higher series ventures. This means that existent companies will most likely be invested, whereas fewer companies are going to enter this market. So, this is a positive side for the companies that are already set in the market (Woodside Capital Partners, 2020).

Thus, due to recent circumstances, these opportunities and challenges projections have been impacted by a negative aspect: more recently, from early 2020, worldwide automotive OEMs and its ecosystem have faced an unexpected crisis due to the COVID-19, bringing repercussions to most economies. In the case of OEMs, if they close or stop the activity, it will influence the entire supply chain, including the path of tech startups that are directly connected to them, focused on their research, development, and innovation as well as Tier-1s that will see a drop in the production demand. According to Deloitte (2020), the pandemic collapse will result in a downshift in global automotive demand, that will presumably trigger the urge to invest in Mergers and Acquisitions and partnerships, which accordingly to Woodside Capital Partners (2020) is already happening, since instead of competing, incumbents are collaborating with tech companies to offset the cost and share resources.

As a potential long-term impact, Deloitte (2020) forecasts that firstly, if countries are in recurring lock-downs, most likely there will proceed an economical global recession, together with a loss of consumers confidence, impacting largely automakers revenue and profitability; secondly, OEMs might redirect their budget to sustain the operational tasks, leaving behind the Research and Development investment; lastly, there might occur delays and lack of stock from suppliers, causing a bottleneck widespread disruption.

In particular, KPMG (2020) relates that the global vehicle sales forecast will drop down to 6-8 percent, compared with the originally expected 0.9%, with a causal sequence in 2021.

In brief, this health situation brings an overall negative impact for the automotive sector, but brings as well new positive opportunities for tech companies: the chance of being acquired by an incumbent and work together for a CASE world, with all the positive opportunities and challenges mentioned in the beginning.

3.2 Vehicle connectivity data needs

In this section, the connectivity data needs are described depending on the scenario of the V2V network, which can vary from moving to stationery, from delay-tolerant to high priority, from car specific to fleet data. Overall, an introduction of Veniam's V2V solution is performed applied to different scenarios and application needs for the specific use cases.

3.2.1 The V2V ecosystem

The V2V ecosystem is composed by the cloud, seeding vehicles (the seeders), and the neighboring vehicles that receive the information (the leechers). The following Figure **3.5** represents how V2V technology happens within Veniam's value proposition. At first (1), OEMs are able to easily set up data in the cloud and distribute it to a few seeders, via cellular or Wi-Fi. Secondly (2), once the seeders receive the update, they proceed to share it with neighboring vehicles, preferably via V2V. Once the information is in the neighboring vehicle, they use it and share it again, via V2V.

These connections are managed through Veniam platform and have the purpose to serve data dissemination value proposition, instead of safety applications. Therefore, they receive the shared data from the cloud and disseminate among the neighboring cars, with different purposes that can be segmented into five use cases.

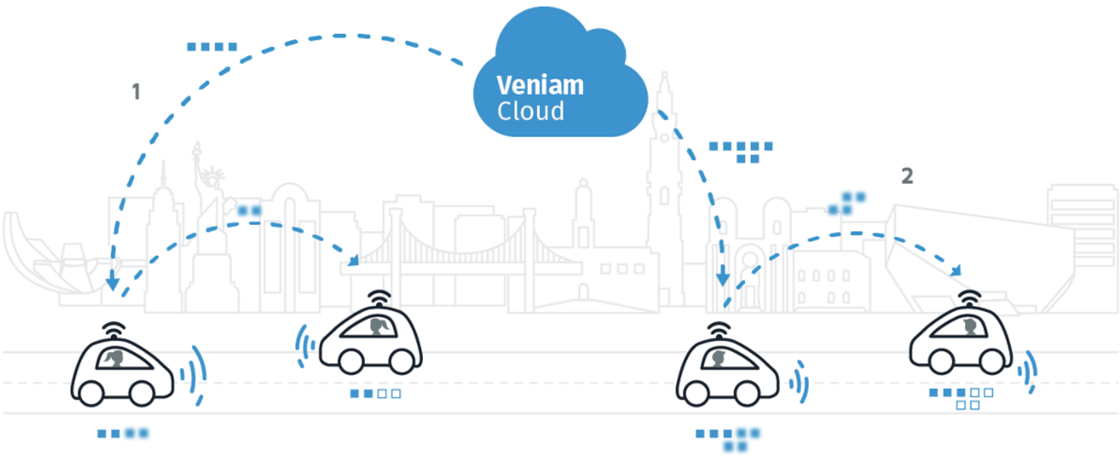


Figure 3.5: V2V content distribution

Firstly, the location for route optimization, map updates, geofencing, vehicle tracking, and fleet management. Secondly, the information for weather, real-time traffic, and road conditions. Thirdly, telematics for real-time parking information and car communication. Fourthly, OTA updates for software updates in parking lots and software updates on-the-move. Lastly, for infotainment and general environmental browsing.

3.2.2 Data volume per consumption

The consumption of vehicle data largely depends on the scenario it is inserted on. A brief overview can be seen in this subsection. Accordingly to Cisco (2019), AVs daily data volume will be 4TB, which corresponds to a daily volume of using 2500 smartphones in 2023.

3.2.2.1 Moving and Stationary

This scenario describes a network of vehicles that are in the move where $speed > 0km/h$, circulating as the normal traffic flows (moving), versus the network of vehicles that are stopped where $speed = 0km/h$, value that is constant over time (stationary).

On one hand, regarding V2V there are higher chances of connecting more efficiently and rapidly in the stationery case, since vehicles are constantly in the same place. Here, the use case is associated with a city parking lot or a OEMs lane after vehicle production. This is a use case with particularly high interest from the OEMs perspective, since they spend millions of dollars with software updates each year and can reduce this value with Veniam's platform, where the software update through V2V reduces largely the software update costs.

As it follows on Figure **3.6**, without Veniam platform, the updates are made manually or exclusively via 4G-LTE. For OEMs this process is both slow and expensive, since they use solely cellular connectivity. With Veniam, a small number of vehicles receive the update through 4G-LTE or Wi-Fi, and these vehicles then share the update with neighboring vehicles using V2V Content Distribution via Wi-Fi or V2X, which result in additional zero cost (explained as well in the previous Figure **3.5**).

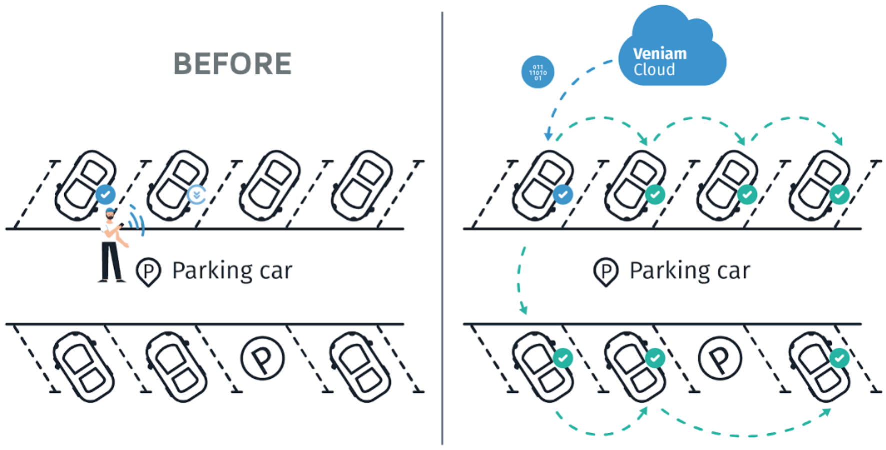


Figure 3.6: Stationary use case: V2V parking lot (left: updating software individually via cell; right: updating software via Wi-Fi V2V)

On the other hand, for moving vehicles to connect, they have to be close to each other (at a relative approximate same speed) or in opposite directions to have the chance of connection. Here, the use case usually is a normal circulation in the city traffic, represented in Figure **3.7**. Then again, firstly, the vehicle A receives the file from the cloud, and secondly Vehicle A sends the file to Vehicle B through Wi-FiV2V.

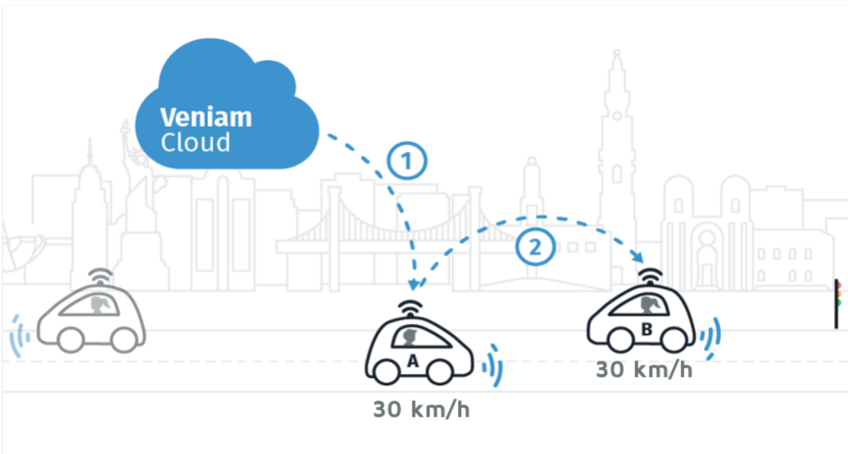


Figure 3.7: Moving in opposite directions use case

Yet, not much information is gathered around this moving use case, which essentially consists of the purpose of the development of this master thesis.

Albeit only two scenarios were presented (the stationary and moving in opposite directions), there can be an hybrid mixture of them, as it follows in scenario 3 and 4:

- **Scenario 1:** Both vehicles are stationary, where $speed = 0km/h$
- **Scenario 2:** Both Vehicles are moving in opposite directions, where $speed > 0km/h$
- **Scenario 3:** Both Vehicles are moving in the same direction, where $speed > 0km/h$
- **Scenario 4:** One vehicle is stationary and the other moving

3.2.2.2 Delay-tolerant and high-priority

File's data can also be classified as delay-tolerant or high-priority. When a file is delay tolerant, it is tolerant enough to wait for the other vehicle to download it, meaning it is needed but not urgent and can be de-prioritised when compared with high-priority files. Nevertheless, it usually has an expiration time within it can be downloaded, a value which is commonly high. Thus, there are many applications that tolerate delay as long as it is guaranteed that the file is delivered. For instance, a map update for a location which is 200km far has 3 hours of delay tolerance.

Notwithstanding, when a file is classified as a high-priority it should be delivered as soon as possible, with an urgent level. For instance, if a car is crossing another and it immediately does a violent move, the data for the other driver is urgent and important for decision making.

In the first case, the delay-tolerant, the file is usually applied to non-safety applications, whereas the second case is applied to safety applications.

3.2.2.3 Car-specific vs fleet data

Data can also be categorised into specific for an exact vehicle range or specific for an entire fleet of a brand. For instance, if considering brand X (total of 6 million vehicles), and supposing they have the model z (1 million vehicles), model t (2 million) and model y (3 million).

If the OEMs decide to share data for car-specific, they will share it only with model z that reaches only 1 out of 6 million of the X car brand. This is considered the car-specific data sharing.

But if the OEMs decides to share data for an entire fleet, it will share for 6 out of 6 million vehicles, meaning that it shares to the entire brand X vehicles. Typical applications in this scenario are diagnosis data, breaks information and GPS. This is considered fleet data sharing.

3.2.2.4 Applications needs

As a result of the research developed so far, it is clear that CASE vehicles will need more and more data consumption since their connectivity needs are increasing. In this subsection, applications are defined and precise data needs are referred. Nevertheless, this research is highly dependent from the different OEMs and different market forecasts for data needs, since it was gathered from insights Veniam has been researching over the past years, with direct input from OEMs, specific industry stakeholders (from OEMs, Tier-1s, and Map Providers) and information from 5GAA and 3GPP.

As mentioned before, applications can differ from delay-tolerant to high-priority, with major impact in the size of the data of the file. On one hand, the delay-tolerant applications are the map updates, the diagnostics such as for the predictive maintenance or non-urgent software updates with exchanges in non-real-time, with different time frequencies (since they are not sent continuously, but with time intervals such as weekly, monthly, etc.).

As this topic is not 100% in accordance with different parties, Table **3.2** oversees the application data needs, ranging from a minimum to a maximum size, as well as the maximum delay tolerance.

Table 3.2: Delay-tolerant applications data needs with maximum delay

Applications	**Minimum Size (MB)**	**Maximum Size (MB)**	**Maximum Delay**
Software update (Critical)	50	5.000	14 days
Software update (Non critical)	1	32.000	7 days
Firmware Update	50	5.000	14 days
Basic Map Update	1.000	1.000	3 days
3D City Model Update	10.000	20.000	14 days
Unit Configuration Update	20	20	14 days
Machine Learning Model	1.000	1.000	14 days
Usage based Insurance	15	500	14 days
Predictive Maintenance	0.015	0.5	14 days
ECU update embedded	1.000	1.000	14 days

On the other hand, the high-priority applications are the ones that need continuous and constant data exchange in real-time, with low latency levels, such as safety applications and streaming services. These high-priority applications are frequently also named as "intolerant applications" (Boban et al., 2018). Therefore, the data rates for download and upload and allowed latency are shown in Table **3.3**.

Table 3.3: High-priority application data needs with data rates and latency

Applications	**Date Rate Download**	**Date Rate Upload**	**Allowed Latency**
Remote car control trajectory	15MB/s	0.5MB/s	100ms
Live remote car control	15MB/s	0.5MB/s	40ms
Cooperative Awareness	5-96Kb/s	5-96Kb/s	100ms
Cooperative Sensing	5-25000Kb/s	5-25000Kb/s	3ms
Cooperative Manoeuvres	10-5000Kb/s	10-5000Kb/s	100ms
Vulnerable Road User (VRU)	5-10Kb/s	5-10Kb/s	100ms
Traffic efficiency	10-2000Kb/s	10-2000Kb/s	>1s
Tele-operated driving	>25.000Kb/s	>25.000Kb/s	5ms
Music Streaming	70MB/h	N/A	3s-5min
Video Streaming	140-1500 MB/h	N/A	3s-5min

As a result of this research, in the methodology section (chapter **4**) it will be described the simulation model, with the choice of two data sizes for the test files to understand the behavior of the impact of the file size in the V2V dissemination for delay-tolerant behaviors. The files sizes chosen were 100MB and 1GB, since they are frequent in these scenarios.

3.3 Vehicle connectivity data costs

As the type of application influences the data needs the vehicle has, the data costs depend on the source they're downloaded by and the quantity of data needed. However, as the volumes increase, the costs related to its conveyance will become progressively important, pressing OEMs to determine who values the data and what is the value of the data. If the purpose is for the end-user, then they should pay. Otherwise, if the gain is for OEMs, then they should assure the cost (Cisco, 2019).

For instance, on a more practical side, Ford and AT&T have collaborated for connectivity purposes: the vehicles are equipped with 4G LTE and built-in Wi-Fi Hotspot. For 20 € a month, in the US, the customer gets unlimited Wi-Fi and cellular data on the vehicle, considering that after 22GB of usage AT&T reduces the speed of traffic (AT&T, 2020). Therefore, in this case, the expenditure benefits the end-user, so the user is the one charged for connectivity.

3.3.1 Cellular

The cellular cost highly depends on the geographical region. Cable.co.uk (2020b) is a source of 1GB cellular cost for individual users worldwide, that analysed information of 6313 SIM-only data, from 230 countries. It's important to highlight that these values are not for vehicle connectivity costs, but it gives a perspective on the countries that experience the cheapest and highest value. Even though Veniam has access to the cell cost information per OEMs, the information is confidential.

Thus, Cable.co.uk (2020b) provides an overview of the minimum, maximum, and average price per 1 GB. Starting from the Asian countries, the median average price is 2.25 €/GB, ranked as the second cheapest worldwide. Though, South Korea ranks as the most expensive Asian country with an average price of 15.12/ €GB, while India presents the cheapest average cost of Data with 0.26 €/GB. Oppositely, both North America and Oceania are ranked as the most expensive regions with median prices of 12 €/GB and 11.5 €/GB respectively. In Europe, there's a mixture of both scenarios, with an average of 6.42 €/GB. While in the northern countries such as Finland (the cheapest in Europe) and Denmark the price per GB is 1.16 €/GB and 1.36 €/GB respectively, in Greece (the highest in Europe) the price goes to 32.71 €/ GB.

Worldwide, the average price of cellular data per GB is around 8.53 €/GB, with the cheapest country being India (Asia) and the most expensive being Zimbabwe (Africa) with 75.2 €/ GB. All the data that led to these conclusions can be found in Appendix **B**.

3.3.2 Wi-Fi

Veniam leverages the unutilised power of city Wi-Fi hotspots. Even though it is not clear what cost do these hotspots charge, the Wi-Fi prices are not as defined as cell prices, since the Wi-Fi offering is estimated by month and not so much by usage (price per GB). Therefore, each Wi-Fi Provider defines its own packages and prices (for instance, in Portugal MEO and NOS), whereas the Wi-Fi aggregators provide a flat fee with credentials for the hotspots.

Wi-Fi Provider Offering In accordance with a study developed by Cable.co.uk (2020a) in 2020, examining 206 countries worldwide, the average price is 83.32 €/month, with the most expensive country being Eritrea in Sub-Saharan Africa (2666.24 €/month) and the cheapest country being Syria in the Near East (6.60 €/month). The most expensive continent is Africa, while the cheapest is Asia and Eastern Europe. In Figure **3.8**, it is showcased the worldwide distribution of prices, ranging from 5 €-20 € to +200 € per month. Nevertheless, these prices can be not exactly the "Wi-Fi" pricing, since the usage allowances and other benefits are not presented in the study, limiting the conclusions of the Wi-Fi pricing. All the data that led to these conclusions can be found in Appendix **C**.

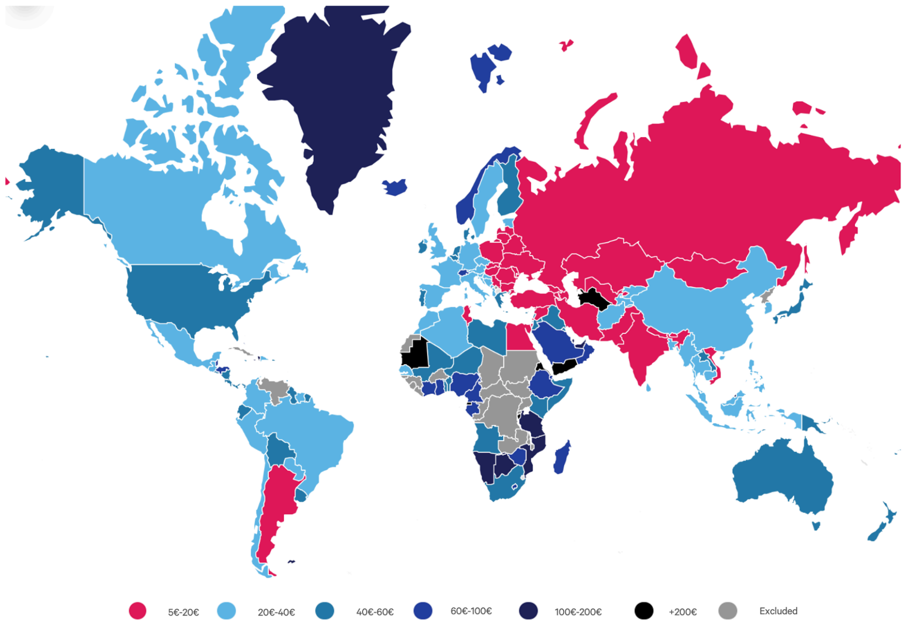


Figure 3.8: Wi-Fi worlwide prices, (Cable.co.uk, 2020a)

Wi-Fi Aggregators Offering In the Wi-Fi aggregators case, they provide a yearly flat rate per device or a subscription for the worldwide network of hotspots, which are around 24.90 € per month (in Portugal). In the case of the city hotspots or private establishments, Wi-Fi can be used for free, with or without an entering code (for instance, Porto's Wi-Fi Hotspot and Starbucks Wi-Fi). Also, the more dense the urban centers, the more free Wi-Fi networks exist that can be used for no fee.

Even though this research was carried with information available online, it should be highlighted that automotive OEMs have access to different price ranges since it is specifically targeted for in-vehicle end-user usage. Lastly, both C-V2X and DSRC are not yet fully defined so there is not much information available regarding the real price per usage.

3.3.3 Comparison

The comparison between the two technologies is complex and delicate, since it has lots of variables that change depending on the country, package, billing plan (per month or per consumption) and limitation of traffic.

Nevertheless, when comparing the download or offload of the same file, it will cost more with cell and less with Wi-Fi, which can sometimes be free. Therefore, Veniam's value proposition is to reduce the vehicular connectivity costs with more robust Wi-Fi usage (that were almost always done with cellular, not reaching the leverage via Wi-Fi).

In the case of V2V, vehicles connect with each other in a mesh, making the most of all the wireless interfaces available from Wi-Fi, to V2X, to 4G or 5GB with the end goal to minimize costs.

As a conclusion, cellular or Wi-Fi costs are taken into consideration when downloading the file from the cloud to the seeding vehicles. After that, the seeding vehicles distribute the information via V2V to the respective leechers.

For that, vehicles should include two Wi-Fi radios - one for the V2I communications and another for V2V communications. If the vehicle only possesses one, Veniam platform allows the user to choose the usage for the radio, either V2I or V2V focused. Most of the vehicles are equipped with one radio only, and that's why the V2I communications are proceeded with cell (from the cloud to seeding vehicles), allowing the space for the V2V Wi-Fi radios utilisation. This allows a cost reduction in V2V communications since the percentage of seeder vehicles is way less than the percentage of vehicles that share the data (the leechers). Therefore, cell cost is used at the beginning (from the cloud to seeders) and at the end (aposteriori) while Wi-Fi V2V cost is used for the file offload.

3.4 Veniam Positioning

3.4.1 Product description

The software Veniam is currently developing is Network Operation Control (NOC), which consists in a cloud-based application for vehicles with network management and smart visualization, including a map that shows in real-time the location of each vehicle equipped with a Veniam OBU. NOC provides information about the amount of data transferred by the different technological communication types as well as metrics and filters that assure it is the "#1 Intelligent Data Networking Platform for connected vehicles and future mobility".

The Veniam offering is divided into two platforms: the dashboard for OEMs and the In-vehicle Dashboard for the user.

3.4.1.1 Dashboard for OEMs

Figure **3.9** represents the NOC initial dashboard, where customer analytics are shown, as well as the devices connected in the network, the Network Configuration, Content Manager, Policy Configuration, and Services.

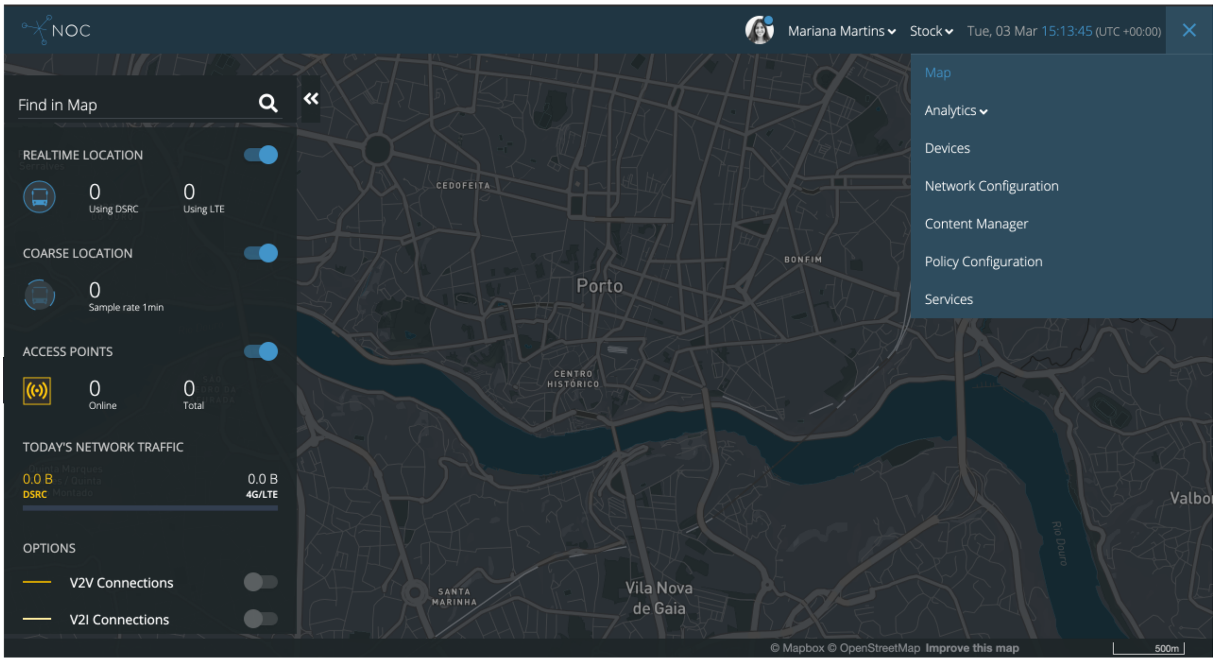


Figure 3.9: Veniam's NOC

V2V definitions are present in the main dashboard, in the "Network Configuration" tab and in "Policy Configuration". Also, in the main page it is seen as an option.

In the initial dashboard, the OEMs can enable the track of V2V or V2I connections in the real-time map.

From the initial dashboard, if pressing the "Network Configuration", the user is able to see what is shown in Figure **3.10** where the user can enable the V2V or the V2I connection as a Wi-Fi mode (in the case the vehicle has 1 radio only), decisions that will impact in the entire network QoS, influencing in the way vehicles communicate with each other.

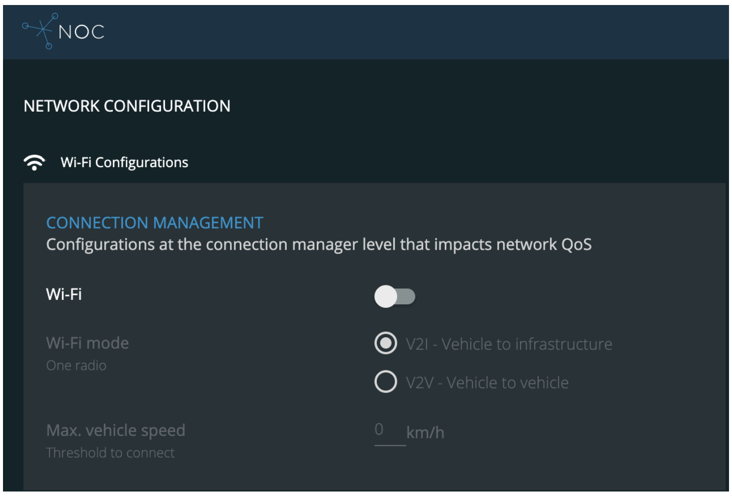


Figure 3.10: Veniam's NOC V2V

In the “Policy Configuration” tab, if creating a new policy, the OEMs is able to decide either if they will enable Wi-Fi V2V or not, which will be taken into account when transferring files, as seen in Figure **3.11**. If not choosing this option, the file cannot be transferred via V2V Wi-Fi, and will most likely be transferred by cell.

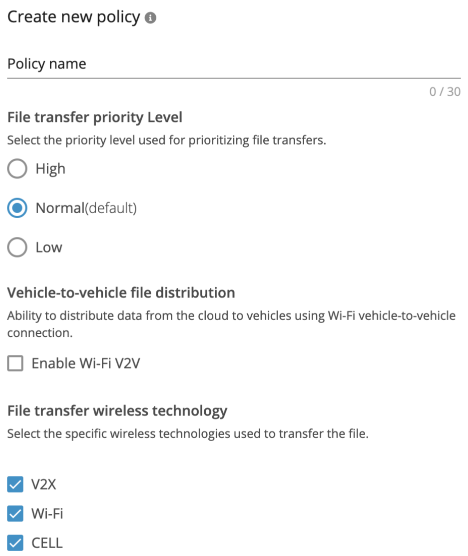


Figure 3.11: Veniam’s policy creation

3.4.1.2 In-vehicle dashboard

In Figure **3.12**, it is represented the in-vehicle dashboard, which is specific to one and only one vehicle and not for the OEMs usage. In the dashboard, the user is able to identify the Vehicle-to-Vehicle Connection and its network traffic and goodput, a live map, track the files sent from the Vehicle to the Cloud, and from the Cloud to the vehicle, as well as a file transfer history.

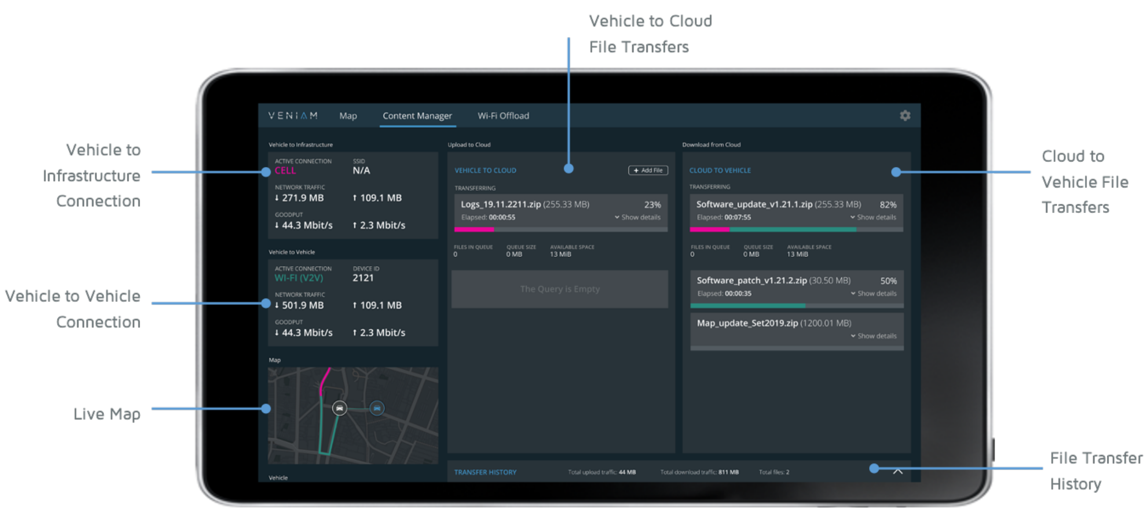


Figure 3.12: Veniam’s V2V in-Vehicle dashboard

Even though Veniam's product is a developed platform, what is key in Veniam offering is the investment in the technology and value proposition that enables these types of communication. For instance, for the V2V use case related to the dissemination of delay-tolerant data, Veniam showcases a cost reduction value proposition to OEMs that so far no other company is considered "direct competition" in this matter. Thus, this Master Thesis outcome is to refine and stand the benefits of the "V2V Veniam Product".

3.4.2 Business benefits

As the vehicle's data needs will grow for the following vehicles, Veniam wants to offer more data, wider coverage, lower cost, and maximum flexibility. From the customer side (the OEMs) they look for new connected services for end-users to provide better in-vehicle experiences to their customers and keep the costs within their own budgets. Even though Veniam customers are OEMs and Tier-1s, the company adds value to the entire supply chain, from manufacturing to sales.

- **Manufacturing:** Better processes with improved logistics and control.
- **Research and Development:** Quality of Experience for passengers while moving massive user data analytics and support for data needs of AVs.
- **Purchasing:** Data Cost Savings.
- **Financial Services:** Data monetization (generating new measurable economic benefits from data).
- **Dealership:** Digital experience in the test drive, without needing to change dealers' Wi-Fi.
- **After Sales:** Upsell digital services with less recalls and new features due to continuous OTA.
- **Sales:** New digital services that generate new revenue streams with global Wi-Fi coverage.

Veniam showcases three use cases of their platform, two of them related to Wi-Fi offload and the last for V2V, which is the most used case for the purpose of this master thesis. Even so, a brief introduction on the first two is given:

(1) "Wi-Fi offload in controlled spaces" showcases additional Wi-Fi connectivity in the vehicle in controlled static scenarios, with cloud-based connectivity management. This is an opportunity for faster Wi-Fi offload of digital features at a lower cost with up-to-date software at all times, transforming the in-vehicle experience in a safe and personalised journey.

(2) "Wi-Fi Offload on the move" leverages the best of the Wi-Fi and cellular networks, with a cloud-based provider, policy, and connection management. Adding to the previous use-case, this one brings the advantage of having updated software on the move transforming the vehicles into more autonomous and smarter means of transport, as mentioned in **3.2.2.1** "Moving and Stationary".

(3) V2V data distribution: With V2V, Veniam utilises the mesh network as a way to disseminate data, allowing vehicles to share data securely and cost-efficiently. The main advantages and business benefits of V2V Veniam product can be seen as:

- **Going beyond Safety Applications**: The current V2V market is focused on the information sharing for safety purposes as brake control or accident prevention, for instance. Though, the applications of sharing data through the same technology but with different purposes are yet not fully investigated or marketed. The product becomes unique in this aspect, for its differentiation in the automotive data sharing landscape.
- **Save on Data Costs:** Adding to the fact that the product acts in the niche of sharing delay-tolerant data, the technology itself (using the Wi-Fi radio for V2V purpose) will allow vehicles to share data with each other, instead of each of them individually download or offload the data from the cloud. This brings a huge impact on costs, since there is less dependency on cellular costs.
- **Make the most out of all wireless interfaces:** The platform leverages diverse wireless interfaces from Wi-Fi, V2X, 4G-LTE, 5G. Veniam prioritises the usage of Wi-Fi at all times, when it is available, but assures the Quality of Service in case the Wi-Fi is missing connection. Therefore, Veniam coverage does not only depend on Telecommunication Operators, but it expands to Wi-Fi Providers.
- **Support Edge Computing with Low Latency:** Edge computing is a paradigm that brings the computation and data storage closer to where it is needed, optimising the responsive times. Thus, low latency means that a machine is able to process a high amount of data with a minimal timeframe. As referred previously in **3.2.2.2**: "Delay-Tolerant and High-Priority", low latency (near real-time access to data) is opposite to delay-tolerant.
  This way, the product enables decentralized networking.
- **Less Dependence on Telecommunication Operators:** As mentioned before, using the vehicle's radio in Wi-Fi V2V mode, it is created the opportunity to create a mesh where vehicles are constantly communicating with each other, sharing data between themselves. Therefore, there is no need for each vehicle to directly download the data from the cloud (via cell). Thus, by having the vehicles become the network, there is less dependence on telecommunication operators.

3.4.3 Customer analysis

For V2V technology to happen, a mesh of more than two vehicles must exist together with the need to offload the same data within a certain region. Thus, interaction from Veniam with another business entity must occur. Thereafter, Veniam establishes a Business to Business (B2B) relationship with its stakeholders.

3.4.3.1 Targeted customer

Even though that at the time this thesis was written the end goal was to have multiple production contracts closed with OEMs, Veniam's software is flexible and adaptive to be inserted in another niche. Though, they have to have one thing in common: the need to offload and share data at a minimum cost (within their own budgets), either on the move or stationary.

Veniam's V2V product is for companies who would like to share data at a lower cost than they do nowadays, a product that unlike other applications allows sharing more than safety data between vehicles, enabling a more connected world. V2V product allows broadening the concept of sharing data as it is known today for safety communication.

Considering the automotive OEMs as the current customer, they are acting globally, from Europe, to Asia, to EUA, with high revenues and a high level of complexity with vast and qualified resources. Therefore, having in mind the stakeholders Veniam has, it is important that the V2V product acts either vehicle-specific, in fleets, or to the entire OEMs. Also, the customer can choose between stationary or on the move V2V transfer. Though, from the history Veniam has, the high interest is on having the V2V technology on the move.

3.4.3.2 Needs of the customer

At first instance, the stakeholder needs to provide value to the end customer. What the automotive OEMs needs, in this case, is to bring additional value to the passenger/driver without highly rearrange their own budgets. Hence, they are looking for ways to reduce costs in the data transference, so that they can explore new business opportunities for their passengers/driver, due to the data that was given with Veniam's software.

Therefore, if the companies understand that Veniam brings a cost reduction in the data offload, then they are able to invest the money to bring additional value to the end-user. Hence, their decision is driven by (1) the cost reduction Veniam provides in data sharing and (2) potential of generating value with the data to the end-user.

This is exactly where Veniam satisfies the need of the customer, by expanding the offering to the end-user, that is indirectly offered by the company. The automotive OEMs decides driven by what would bring and impact in their overall communication costs and what would bring additional value to their end-users (driver and passenger). The most highlighted needs are the after-sales services, with applications such as software updates, map updates, unit configuration update, and road condition video data. There is also interest in entertainment services (for music and video streaming), but not as much as the previous one. Then again, it's important to highlight the versatile potential of the V2V product, since it could adapt to different automotive niches, rather than OEMs and Tier-1s only. Figure **3.13** illustrates the relation and value proposition of Veniam's stakeholders as described before.

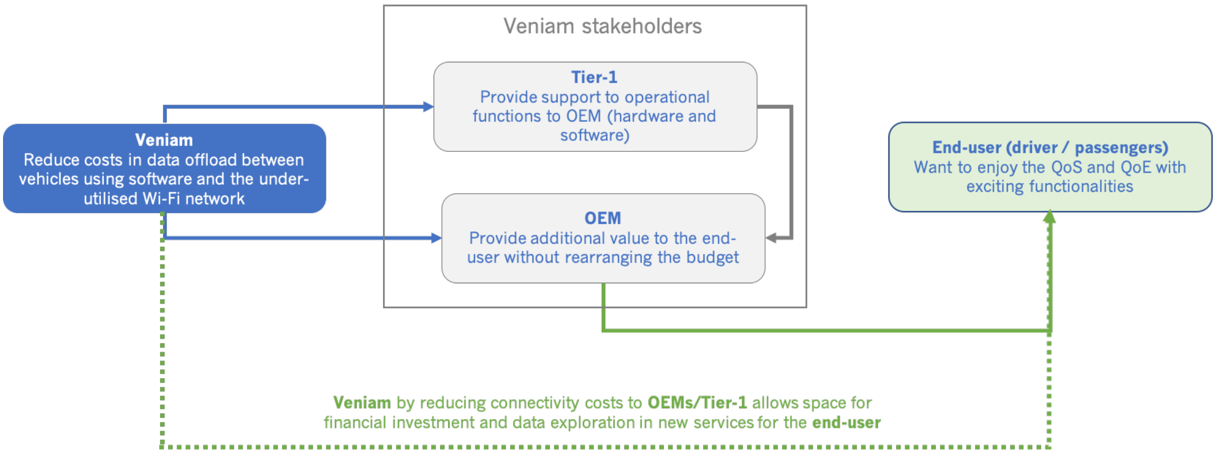


Figure 3.13: Veniam's stakeholders relation and value proposition

3.4.4 Competitive landscape

As far as the product is currently developed, the product isn't a threat to any company and its technology is unique. This means that there is no offering on the V2V technology as for non-safety applications in the market.

A competitive analysis was performed to understand the position Veniam has in the market. The companies were categorised into 3 classes: direct, indirect competition, and partnership. Even though there are no similar products in the market, direct competition is considered the one that has the potential to overlap Veniam. The indirect competition is the result of companies that have products that are substitutes. The partnership category defines the companies that would value from o collaboration with Veniam.

Adding to this classification, the companies were divided depending on the threat they represent to Veniam (from 0 to 5), answering the following questions/ statements (if yes=1, if not=0) :

1. Do they have software to obtain vehicle personal data?
2. Do they have a platform to manage/share vehicle data?
3. Use Case: Wi-fi Offload in controlled spaces
4. Use Case: Wi-fi Offload on the move
5. Use Case: V2V content distribution for non-safety

Overall, 55 companies were analysed and categorised into those classes. Regarding the location, most of the companies are from EUA (29 out of 55). Regarding the sector, the majority acts in the automotive industry (24), IT Tech (7) and, IoT Services (6). Albeit most of the companies are independent, some of them were acquired by tech companies such as T-Mobile, Cisco, Bosch, Samsung Electronics, Continental, or Aptiv.

The 3 highest ranked companies per category are presented, even though the entire market research can be found in Appendix **D**.

3.4.4.1 Direct competition

The following companies all have a platform as a product.

- **Carnegie Technologies** - Developed the NCP (Network Convergence Platform) which is a Connection Manager with Intelligent Network Selection that provides a better user experience on the move, shifting between cellular, Wi-Fi, satellite, and other networks. Their embedded software oversees the quality of all the available networks and selects the best choice based on the policies (Carnegie Technologies, 2020).

  Even though this technology is not applied in vehicular communications but in mobile, the technology behind is similar to Veniam's.
- **Aeris Communications** - Developed the Aeris Mobility Suite that delivers the software components needed to build and monetize an entire connected vehicle program (with personalisation depending on the region and customer)(Aeris, 2020).
- **Movimento Group** - Developed the Movimento OTA Platform, which is software lifecycle management to keep vehicles upgraded with the latest software development with scalable software management, big data analytics, and cybersecurity technology (Movimento, 2020).

3.4.4.2 Indirect competition

- **ETAS** - Developed the ETAS AUTOSAR (AUTomotive Open System Architecture) Solutions with the end goal of establishing a common language on software architecture, application interfaces, and methodology of embedded software for vehicle electronics. This solution is a workforce between the major automotive industry OEMs and suppliers (ETAS, 2020).
- **Commsignia** - Developed the Commsignia V2X Software Stack, which is an embedded solution that provides a modular framework for diverse resource-constrained target platforms, with developer-friendly features that ease the development and integration process to any hardware

platform (Commsignia, 2020). Commsignia focuses on supporting the development of safety-critical applications and not so much the delay-tolerant services.

- **Jasper Technologies** - Developed the Cisco IoT Control Center, which is a platform to make connectivity more cost-effective and reliable, managing the device lifecycles, with real-time visibility, fixing bugs on the spot, without worrying to call the service provider (Jasper Technologies, 2020). Albeit Jasper doesn't mention its focus in vehicular communications, their software is capable of doing so.

3.4.4.3 Partnership

- **Connected Cars** - Developed the Connected Cars device which is a hardware unit easily installed in most vehicles manufactured after 2008, which collects raw vehicle data - making owning, driving or maintaining a car much simpler. Adding to that, they developed the fleet dashboard and driver app, which provide the end-user with proactive vehicle care (Connected Cars, 2020).
- **Automatic** - Developed Automatic - Connected car assistant, which is an app that allows the user to know more about the road condition (Automatic, 2020).
- **Bittium** - Developed automotive intelligent and secure software development, which are designed directly for OEMs and users (Bittium, 2020).

Even though there are diverse companies acting in Veniam's sector, its value proposition is still what distinguishes Veniam from its competition. Also, on the V2V non-safety delay-tolerant applications, there was no company found with a similar offering. To understand the competitiveness of V2V product, a SWOT analysis was produced, as shown in Figure **3.14**:

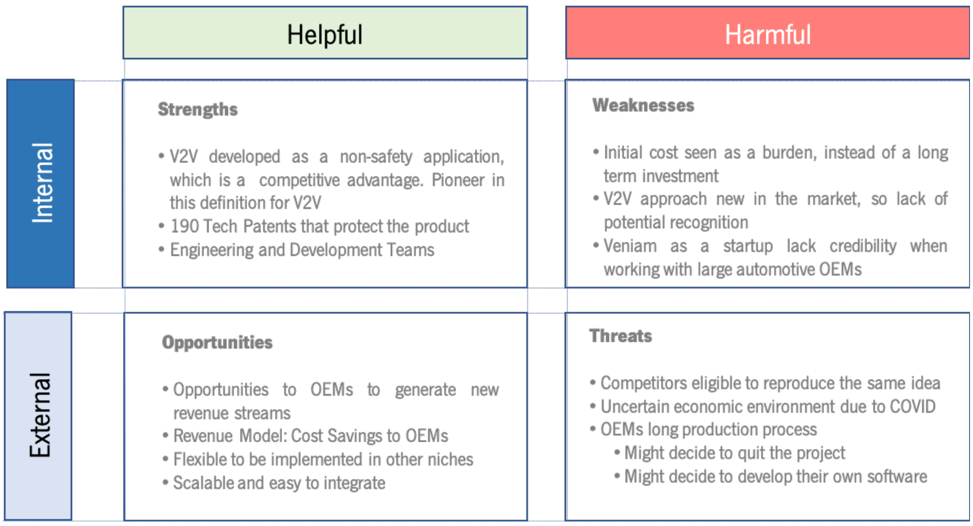


Figure 3.14: Strengths, Weaknesses, Opportunities and Threats to Veniam's V2V Product

3.4.5 Financial analysis

Veniam's value proposition is to reduce costs in the data offload: instead of using cell all the time, the platform allows wider Wi-Fi connectivity, as shown in Figure **3.15**.

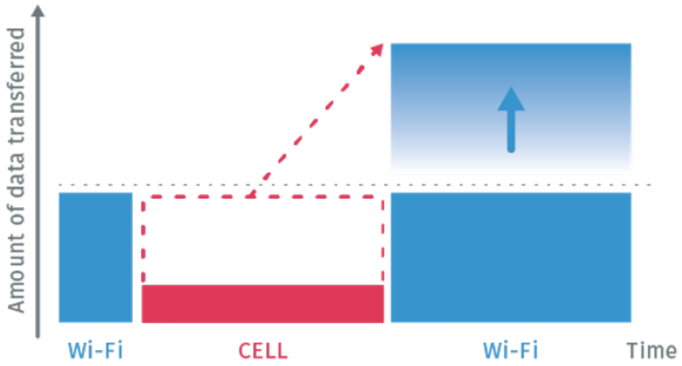


Figure 3.15: Data source utilisation impacts data costs

Veniam's pricing model has two components. On one hand, there is a one-time license fee that is paid upon the deployment of the software. On the other hand, a subscription fee based on the data volume needed by the stakeholder. The main variables of the price depend on quantity (the more the number of vehicles equipped, the lower the license price), the usage (an annual fee that is based on data offload (savings) per vehicle) and feature set (depends on the features included in the personalised package).

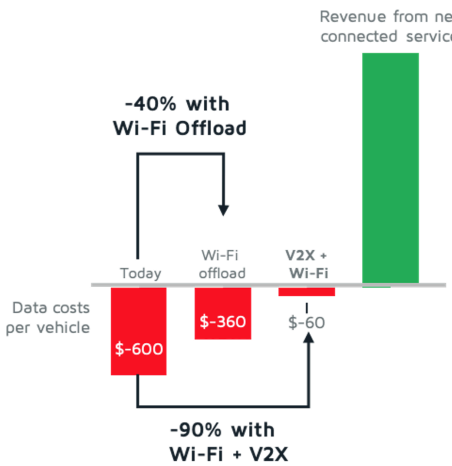


Figure 3.16: Savings on data using Veniam's solution Wi-Fi + V2X

In Figure **3.16**, it is showcased the impact that the Veniam platform brings to the company.

1. At first, one can oversee that the data costs per vehicle as to the "today", using only cell data;

2. With the offering of the first use case (the Wi-Fi Offload only), Veniam assures a cost reduction of -40% in relation to the previous scenario with only cell utilisation;
3. Adding to that, including the V2X offering (which includes V2V, Veniam assures a decrease of an additional 50%.
4. At last, and as stated before, with this decrease in data cost-sharing, OEMs are now able to generate revenue from new connected services. Therefore, the product enhances the value creation of OEMs' end-users.

In the particular case of V2V product, costs to the OEMs are calculated as follows:

If **offload only with cellular**:

$$File\,Size\,(MB) \times Quantity\,of\,Vehicles \times Cell\,Cost\,(MB) \tag{3.1}$$

The quantity of vehicles corresponds to the number of vehicles in the entire mesh. In the case of the following simulation, all of the vehicles.

With **Veniam V2V Solution**:

$$File\,Size\,(MB) \times Quantity\,of\,Vehicles\,Using\,Cell \times Cell\,Cost\,(MB) \tag{3.2}$$

Therefore, the cost reduction is given as:

$$Offload\,with\,Cellular - With\,V2V\,Solution = \,Cost\,Reduction \tag{3.3}$$

For instance, considering the scenario that the file has 50MB, the mesh has 1000 Vehicles and the cell cost is 0.10 €/MB, then the total cost only using cell offload would be:

$$50 \times 1000 \times 0.10euros = 5000euros \tag{3.4}$$

Considering that using Veniam, 60% of the vehicles can offload via Wi-Fi, then out of 1000, 600 vehicles offload via Wi-Fi while the other 400 offload via cell.

$$50 \times 400 \times 0.10euros = 2000euros \tag{3.5}$$

$$5000euros - 2000euros = 3000euros \tag{3.6}$$

The Wi-Fi costs or V2V Wi-Fi cost is not considered in the equation due to its granularity when compared with cell prices. Mostly, because the Wi-Fi connection is usually from public access city Wi-Fi hotspots. The utilisation of NOC assures a positive cost reduction, as shown in Figure **3.6**.

3.4.6 Strategic fit

On one hand, the strategic fit oversees the match that a company is doing between its resources and capabilities with the opportunities seen in the market.

On the resources and capabilities side, Veniam possesses a strong IP Portfolio, differentiating its position in the market, assuring the safety of the technology. The resources are highly developed for automotive usage, but have the flexibility to be implemented in different scenarios, depending on what the customer needs. Hence, adding to the fact that the product is versatile and personalised for the user, it has a highly competent engineering team behind, guaranteeing the full support to a perfect development and implementation. Thereafter, Veniam maintains the organisational framework suited for the niche of its stakeholders, as well as the capabilities needed to implement the strategy adapted to the needs of the market.

3.4.7 Conclusion on V2V market fit

This subsection consolidates the entire product analysis made previously. The market opportunities are related to the business benefits mentioned in **3.4.2**. Though, the market opportunities take into account the attractiveness of the business benefits.

Hence, the increasing needs for vehicular connectivity on a mesh network are raising interest from the automotive OEMs side, where Veniam contributes to a CASE vehicular reality that satisfies its stakeholders.

Connected Data privacy has been a concern most users have regarding the utilisation of CASE vehicles, since soon data sharing will be a reality. It enables vehicles to make the most out of the available networks while ensuring the access of data flows with the right QoS and security levels. Thus, Veniam possesses a secure platform capable of tackling data privacy user pain.

Autonomous The autonomous driving is improved, by maintaining a strong connection with up-to-date data, without the user having to worry with that in the first place (connecting to cell or Wi-Fi manually). Also, it enables the share of more data for ADAS developers, to constantly improve and perfect the insights.

Shared Veniam oversees a reality where EVs and e-bikes are a part of the city mesh by being shared, offering better-managed fleets with superior mobility services with personalised digital experiences.

Electrical While on the move with an EV, the driver is now able to seek for economical battery usage and charging stations. While not on the move (for instance at the charging stations), the user is now able to offload data, enabling new opportunities for the OEMs side.

A summarized table containing the analysis can be seen in Table **3.4** in the following page.

3.5 Reflection on the Product Analysis

The case description and critical analysis chapter is the foundation and consolidation for the test environment that follows in the subsequent chapters, the methodology and results.

In theory, V2V technology is promising and, with the correct investment in research and development, it can lead to new innovative roads of connectivity.

With the support of this overall positive product analysis, follows the methodology and results from the simulation carried with a mesh of a fleet of 356 vehicles in Porto, Portugal. These results will indicate either if the technology has practical potential or not, depending on the different parameters chosen that can reflect different niches or applications (e.g.: file size, chunk size, seeding strategy).

Table 3.4: Summarised Product Analysis

Topic	Benefitial Aspects	Unfavorable Aspects
Automotive Landscape	• 25% of miles traveled in the USA estimated to be with CASE vehicles • Automotive tech companies see a decrease in seed funding (meaning there are fewer competitors in the market), but an increase in higher series development leading to an opportunity to be merged and acquired by an incumbent	• Pandemic situation dropped down the acquisition of the vehicles; • Innovation investments were deprioritised when compared with the production costs • Governments not prepared with infrastructure for the CASE reality.
Vehicle Connectivity Data Needs	• By 2023 it is estimated that AVs will offload 4TB daily, with an increasing need to offload delay-tolerant non-safety data; • Data needs can be made while on the move or stationary; with delay-tolerant or high priority data; car specific or fleet data	• Possibility of hacking the vehicle system with the big data offload: data safety issues are a big user concern.
Vehicle Connectivity Data Costs	• Increasing availability of Wi-Fi Hotspots in worldwide cities, leading to a decrease in Wi-Fi data costs • Wi-Fi doesn't depend on the amount of offloaded data	• Cellular and Wi-Fi costs highly dependent on location • No clear price comparison due to the differences in a package offering
Business Benefits	• High interest on V2V technology on the move, with savings on data costs, while making the most out of all the wireless interfaces, with less dependence on telecommunication operators;	• Credibility to stakeholders, since Veniam is a startup and V2V product not as implemented in the market as the Wi-Fi Offload Use Case
Customer Analysis	• Currently, OEMs and Tier-1s, but the product has the flexibility and agility to adapt to different niches, generating new value streams	• OEMs long production process, delaying the implementation of innovative technology.
Competitive Landscape	• No equivalent product in the market; • Product protected by tech patents;	• Competitors eligible to reproduce the same idea, but with fewer features
Financial Analysis	• Savings after first investment, assuring at all times a cost reduction	• Initial investment
Strategic Fit	• Repurpose V2V communications to non-safety applications • Strong IP Portfolio, that protects the product;	• Distance and personalised implementation might lead to errors.

Chapter 4

Methodology

From the research done in the review of the literature and the critical analysis performed on the last two chapters, the product is now described analytically in the scope of theoretical feasibility. The process of interpreting the simulations tests that led to the V2V results is performed in the following two chapters. The current one summarizes the methodologies utilised to overcome the identified challenges.

4.1 Product terminology on V2V

A brief explanation of each useful V2V term used for this project context can be seen below, ordered alphabetically.

Table 4.1: Product terminology on V2V

Term	**Description**
Chunk	A fragment of a file of a well-defined size. A user is able to select the size of the chunk in the cloud as a policy and translate it to vehicle file transfer decisions. For instance, if a file has 100MB of size, it might have 100 chunks of 1MB.
File	A collection of data stored in one unit, with a known size, identified by a filename and eligible for a File Transfer. It can be of any format, but is only visualized in the cloud dashboard in certain formats (png, jpg, bmp, gif, pdf, txt).
Leecher	Is the vehicle who benefits from the information provided by the seeder (definition below). The leecher does not offer anything in return to the seeder, but it can expand the number of leechers in the network by sharing the file via V2V.
Seeder	Is the vehicle that firstly receives a part of the file from the cloud through cell and shares it with other vehicles (leechers), using V2V.

Albeit it was not considered in the scope of the current simulation model for the master thesis project, Time to First Byte is a concept that also needs to be highlighted.

It is the time since the beginning of the last scan until the time when the first application byte is sent and acknowledged, excluding the duration of any sessions that use different access points and happen between the current association and the last scan, as represented in the scheme below in Figure **4.1**, divided into X, Y and X+Y stages.

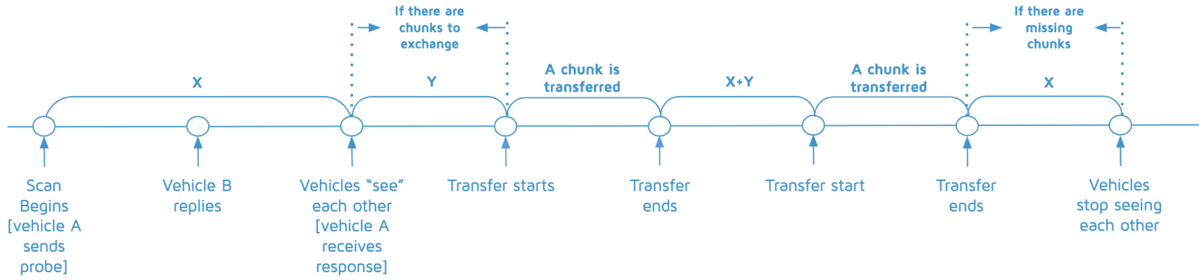


Figure 4.1: V2V time sequence of connection and offload

X stage: This first stage is described as an initial knowledge of the vehicles, where they send and receive probes and where vehicle A asks vehicle B if it has the necessary chunks to complete the offload. The process starts with a scan where vehicle A sends a probe to vehicle B. Then, vehicle B replies, meaning that the vehicles can see each other.

Y stage: Then, in case that vehicle B responded that it doesn't need those chunks, vehicle A checks for more opportunities in case that there are more vehicles nearby.

In the case vehicle B needs those chunks, then the process of transference starts and the first chunk is transferred.

X+Y Stage: It is a pre-configured time, which is around 10 ms. Depending on how long it takes to send and receive probes, the vehicle will broadcast for the remaining time.

So, in between chunks offload, there is this X+Y time of bottleneck. Then, after X+Y, another chunk is transferred. Since X+Y occurs periodically, it is possible that it overlaps with the transfer itself. Lastly, after the chunks are sent, the transfer ends and returns to stage X if there are missing chunks. When the respective chunks are delivered, the vehicles stop seeing each other, meaning that vehicle A no longer receives a response from B.

4.2 Simulation

In this subsection, an overview of the simulation is provided, describing the testbed, the assumptions, the seeding strategies, the programming environment, where parameters are showcased.

4.2.1 Testbed description

To test the opportunities of connection using V2V in a mesh, the ideal outline is where vehicles are encountering amongst themselves several times, increasing the number of opportunities to exchange data chunks. Consequently, the higher the city density, the higher the chance of disseminating a file more instantly, and the lower the city density, the less impact it has using V2V technology.

Hence, a simulation was done gathering the data of 356 vehicles from STCP (Sociedade de Transportes Coletivos do Porto) moving in the city center of Porto, Portugal. This is one of the most important assets Veniam has, since the company can get real-time information about the position of the vehicles every day.

In the particular case of this simulation, a dataset of one entire day was used to obtain the results.

4.2.2 Assumptions

Assumptions were considered for the simulation: general assumptions that relate to the overall environment, seeding, and chunking assumptions.

The general assumptions considered are:

- A vehicle has 2 Wi-Fi Radios, one in client mode that allows to get data from APs or other vehicles. The other in an ad-hoc mode that allows other vehicles to connect to it and getting chunks from it as needed;
- Neglecting possible interference between the two radios of the same vehicle;
- The simulation analyses the data from one-day traffic performance, meaning that the vehicle has 1 entire day to deliver the file (delay-tolerance);
- When the simulation begins, all vehicles are "asleep", meaning that their ignition is not on;
- For the first use case ("Impact of file fragmentation amongst vehicles"), if the file is divided amongst vehicles, it is assumed a high level of complementarity of the chunks (E.g.: In the scenario of having 2 vehicles, each one with 50% of the file, these 50% chunks are different from one vehicle to the other).

The seeding assumptions considered are:

- A leecher only gets data from 1 seeder at a time;
- Various leechers can get data from the same seeder at a time.

The chunking assumptions considered are:

- The order of chunks to get from a peer is chosen randomly within the chunks that are novel to the vehicle;
- Chunks never arrive corrupted;
- Moving vehicles can get chunks from parked vehicles;

- Parked vehicles can get chunks from moving vehicles;
- Control messages for understanding which chunks a peer can provide to a vehicle are instantaneous and occur immediately after Time to First Byte (TTFB).

4.2.3 Seeding strategies

The seeding strategies consist of deciding which vehicles are the seeders in the network. Based on the literature review and the simulation model created, three strategies are described in Table **4.2**.

Table 4.2: Seeding strategies description

Strategy	**Description**
Random Selection	Entirely random vehicles are chosen as seeders independently of their activity (even if they are ignited or not).
Weighted Selection	Random vehicles with the probability of a vehicle being a seeder being proportional to the activity time of the vehicle are selected as seeders.
First Come First Served (FCFS)	The first x% of vehicles to ignite are selected as seeders. This strategy has the limitation of selecting always the same vehicles, independently of the number of testing done in the simulation, making it into a biased result.

4.2.4 Programming environment

The simulation was developed in Julia (.jl), which is a high-level, high- performance programming language, more focused on numerical analysis and computational science.

4.2.4.1 Parameters

In the simulation, various parameters were defined.

Fixed parameters

Firstly, after the strategies were configured, they were given an attribute.

```
ssFCFS = 1      #first come first served
ssRandom = 2    #random vehicles
ssWeighted = 3  #random vehicles weighted by their activity
```

Then, the APs and vehicle sample can be defined, as well as the V2X mode.

The “apsample” is the percentage of APs to sample from]0,1] (if 0 it disables V2I). The “vehiclesample” is the percentage of vehicles to sample]0,1] (in this case, if 1, equals to 356 vehicles and if 0.5 equals to 178 vehicles). The “v2xmode” is accountable to define the type of communication between vehicles (in this case, V2V).

```
apssample = 0.1, #can vary from [0.1, 0.25, 0.5, 1.0]
vehiclessample = 1, #can vary from 0.1:0.1:1.0
v2xmode = [v2v]
```

Then, more specifically for V2V, there were fixed and variable parameters. The fixed ones, meaning they did not change alongside with the testing on the dataset.

The “v2vrange” defines the range in meters that each vehicle can communicate with each other. The “v2vthpt” is the V2V throughput in MB per second, assuming a constant throughput at all times. The “v2vttfb” is the V2V TTFB in seconds. The “v2vmaxspeed” is the maximum speed supported by V2V in Km per hour.

```
v2vrange = [40.0]
v2vthpt = 1.0
v2vttfb = [3]
v2vmaxspeed = [30]
```

Also, to define if a vehicle is parked or on the move, other fixed variables emerged: The “minparkingtime” is the minimum GPS gap in seconds to be considered parking, while the “maxparkingtime” is the maximum time a vehicle stays active when parked. The “maxparkingspeed” is the maximum speed (exclusive) for parking to happen. The “maxparkingdist” is the maximum allowed distance (meters) between parking samples.

```
minparkingtime = 60*5 #defined as 5 minutes
maxparkingtime = 0
maxparkingspeed = 5.0
maxparkingdist  = 100.0
```

Variable parameters

Then, the actual parameters that needed change and iterations were the variable ones as seen below.

The "rndseed" is the number of repetitions each definition is run, chosen randomly in the mesh (in the case of this simulation, it was tested with 10 and 20). The "seedingstrat" is the strategy defined, which is only used if pseeders < 1. The "pseeders" is the percentage of vehicles that are seeders, while the "pchunks" is the percentage of file size each seeder gets. Lastly, the "file-size" is the size of the file to transfer in MB, while the "chunk-size" is the size of the chunk in MB (if choosing 0, the chunking is disabled).

```
rndseed = 1:{10} or {20}
seedingstrat = {ssRandom}, {ssFCFS} or {ssWeighted}
pseeders = ]0,1[
pchunks = ]0,1]
file-size = {100} or {1000}
chunk-size = {1} or {5} or {10}
```

Input: Mesh Network Scenario
for *rnseed x seedingstrat x pchunks x file-size x chunk-size* **do**
    for *pseeders* **do**
        Calculate Wi-Fi V2V Offload percentage
        Calculate Cell seeded percentage
        Calculate Cell Aposteriori percentage
        Store mean, standard deviation, superior, inferior value
    end
end

Algorithm 1: V2V Offload simulation algorithm

4.3 Use cases

For this experience, two use cases were considered leading to two experiments as seen in Figure **4.2**: the first, focused on the impact of file fragmentation amongst vehicles; the second focused on the impact of file replication amongst vehicles, both using V2V technology. From this stage on, the percentage of file per seeder abbreviates to PFPS, and number of seeders to nseeder.

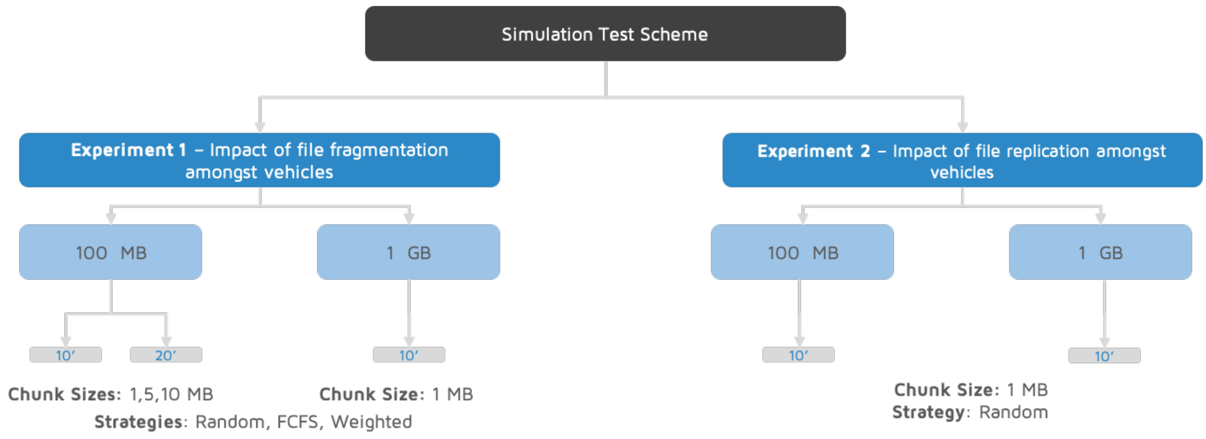


Figure 4.2: Simulation test scheme

4.3.1 Impact of file fragmentation amongst seeder vehicles

The use case of file fragmentation amongst seeder vehicles corresponds to the first experiment. In this experience, the entire file is divided between the selected seeders. Thus, the sum of the sizes of the chunks of all the seeders equals to the entire file size.

File size As seen in the scheme, the experiment was led with two file sizes: 100 MB and 1GB[1], selected based on the literature review done in what concerns delay-tolerant non-safety applications data needs, referred in Table **3.2**. This choice of sizes allowed to understand the impact in the V2V offload depending on the file sizes.

Thus, as this experiment requires the division of chunks, the divisors of both 100 and 1000 were considered, so that the chunks (considering the minimum chunk size is 1MB) can arrive clean and not corrupted to the end destination.

So, for the case of 100MB file it is outlined that out of 356 vehicles, the maximum of seeders available is 100 vehicles since 1 is the minor divisor of 100. For instance, if having 1 seeder in the network, the vehicle gets 100% of the file, whereas if having 100 seeders in the network, each vehicle gets 1% of the file.

The nine options of file distribution with 100MB among vehicles can be seen in Table **4.3** below.

Table 4.3: Experiment 1 - PFPS per nseeder (100MB)

N° of seeders	1	2	4	5	10	20	25	50	100
% File per seeder	100%	50%	25%	20%	10%	5%	4%	2%	1%

[1] 1GB was considered 1000MB instead of the real value of 1024MB, to smooth the data analysis

In the case of the 1GB file, the divisors of 1000 include the ones mentioned in the previous table, plus the 8, 40, 125, 200, and 250.

Hence, for the case of the 1GB file, it is outlined that out of 356 vehicles, the maximum number of seeders is 250, since it is the major divisor of 1000 (considering that it can go only up to 356).

Then, if having 250 seeders in the network, each one of them will have 0.4% of the file.

The fourteen options of file distribution with 1GB among vehicles can be seen in Table **4.4** below.

Table 4.4: Experiment 1 - PFPS per nseeder (1GB)

N° of seeders	1	2	4	5	8	10	20	25	40	50	100	125	200	250
% File per seeder (%)	100	50	25	20	12.5	10	5	4	2.5	2	1	0.8	0.5	0.4

Repetitions For each of the file sizes and strategies, the simulation was run 10 and 20 times to understand the impact of repetitive input in the results. It was found that repetitions do not add a novel insight into the results (showcased in the results - chapter **5**).

Chunk size To understand the offload success rate, the chunk size was varied from 1MB, 5MB to 10MB. It was found that 1MB chunk size brings the better V2V offload (showcased in the results - chapter 5).

Strategies used All the strategies were tested in the first experiment: Random, Weighted, and FCFS.

Considering the example of the file fragmentation with a 100MB file and chunks with 1MB, the division of the file per seeders is as it follows on Figure **4.3**.

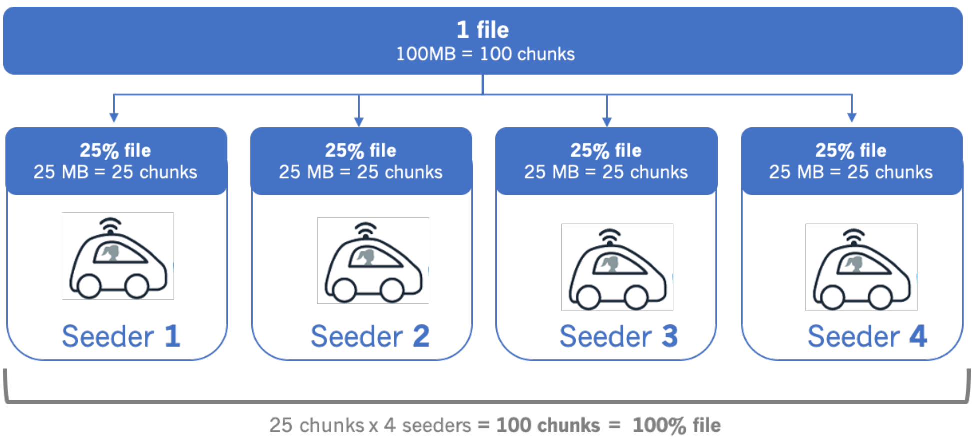


Figure 4.3: File fragmentation amongst seeder vehicles

4.3.2 Impact of file replication amongst seeder vehicles

The use case of file replication amongst seeder vehicles corresponds to the second experiment. In this experience, some chunks of the file are replicated between the selected seeders. Thus, the sum of the sizes of the chunks of all the seeders is bigger than the entire file size.

File size Both the 100MB and 1GB file were also used for the second experiment, with the same amount of seeders described in Tables **4.3** and **4.4**. So, for the 100MB it was tested with 1, 2, 4, 5, 10, 20, 25, 50 and 100 seeders and the 1GB tested with 1,2 ,4, 5, 8, 10, 20, 25, 40, 50, 100, 125, 200 and 250 seeders. The difference between Experiment 1 and Experiment 2 is the PFPS. While in the first the percentage of a file was divided between seeders, in this experiment the chunks of the file are replicated to reach more vehicles. Thus, the PFPS is what defines the difference between the first and second experiments.

100MB The PFPS for the 100MB was defined as 100% and $2^n\%, with\, n = [1, 6]$ corresponding to 2%, 4%, 8%, 16%, 32% and 64%. The selected values for $n = [1, 6]$, were considered since $2^7 = 128$ and the maximum tested was 100% PFPS.

If the $minimum\, value(\%) < 2^n\, with\, n = [1, 6]$, then it is tested from that value on.

For instance, in the case of having 100 seeders, the minimum percentage to offload the file is if each vehicle has 1% of the file. Then, in this experiment, it was tested from 2% until 100%.

Though, in the case of having 2 seeders, the minimum percentage to offload the file is if each vehicle has 50% of the file. Then, in this experiment, it was tested for 64% and 100%.

The overall view for Experiment 1 with the file size of 100MB can be seen in Table **4.5**. In the results chapter, it will be highlighted an additional PFPS, since there was an exploration around what would be the ideal value to offload the file.

Table 4.5: Experiment 2 - PFPS per nseeder (100MB)

N° of seeders		1	2	4	5	10	20	25	50	100
Minimum (%)		100%	50%	25%	20%	10%	5%	4%	2%	1%
% File per seeder	2%	-	-	-	-	-	-	-	-	**x**
	4%	-	-	-	-	-	-	-	**x**	x
	8%	-	-	-	-	-	**x**	**x**	x	x
	16%	-	-	-	-	**x**	x	x	x	x
	32%	-	-	**x**	**x**	x	x	x	x	x
	64%	-	**x**	x	x	x	x	x	x	x
	100%	**x**	x	x	x	x	x	x	x	x

1GB The PFPS for the 1GB was defined as 100% and $0.01 \times (2^n), with\, n = [2, 9]$, corresponding to 0.4%, 0.8%, 1.6%, 3.2%, 6.4%, 12.8%, 25.6%, 51.2% and $2^n, with\, n = [1, 6]$ corresponding to 2%, 4%, 8%, 16%, 32%, 64%. The selected values for the first expression for $n = [2, 9]$, were considered since $0.01 \times 2^2 = 0.4\, and\, 0.01 \times 2^{10} = 102.4$ since the minimum PFPS tested was 0.4% and the maximum was 100% file per seeder.

The same thinking process applies to this file size, where if the minimum percentage to offload is minor that the percentages tested $0.01 \times 2^n, with\, n = [2, 9] or 2^n, with\, n = [1, 6]$

For instance, in the case of having 250 seeders, the minimum percentage to offload the file is if each vehicle has 0.4% of the file. Then, in this experiment, it was tested from 0.4% until 100%.

Though, in the case of having 2 seeders, the minimum percentage to offload the file is if each vehicle has 50% of the file. Then, in this experiment, it was tested for 51.2%, 64%, and 100%.

The overall view for Experiment 2 with the file size of 1GB can be seen in Table **4.6**. As well as for the 100MB file, in the 1GB file, there was some exploration besides the percentages defined, to understand what would be an ideal value.

Table 4.6: Experiment 2 - PFPS per nseeder (1GB)

N° of seeders		1	2	4	5	8	10	20	25	40	50	100	125	200	250
Minimum (%)		100	50	25	20	12.5	10	5	4	2.5	2	1	0.8	0.5	0.4
% File per seeder	0.4%	-	-	-	-	-	-	-	-	-	-	-	-	-	**x**
	0.8%	-	-	-	-	-	-	-	-	-	-	-	**x**	**x**	x
	1.6%	-	-	-	-	-	-	-	-	-	-	**x**	x	x	x
	2%	-	-	-	-	-	-	-	-	-	**x**	x	x	x	x
	3.2%	-	-	-	-	-	-	-	-	**x**	x	x	x	x	x
	4%	-	-	-	-	-	-	-	**x**	x	x	x	x	x	x
	6.4%	-	-	-	-	-	-	**x**	x	x	x	x	x	x	x
	8%	-	-	-	-	-	-	x	x	x	x	x	x	x	x
	12.8%	-	-	-	-	**x**	**x**	x	x	x	x	x	x	x	x
	16%	-	-	-	-	x	x	x	x	x	x	x	x	x	x
	25.6%	-	-	**x**	**x**	x	x	x	x	x	x	x	x	x	x
	32%	-	-	x	x	x	x	x	x	x	x	x	x	x	x
	51.2%	-	**x**	x	x	x	x	x	x	x	x	x	x	x	x
	64%	-	x	x	x	x	x	x	x	x	x	x	x	x	x
	100%	**x**	x	x	x	x	x	x	x	x	x	x	x	x	x

The repetitions, chunk size, and seeding strategies used for Experiment 2 are based on the results from Experience 1.

Repetitions Each simulation was run 10 times.

Chunk size The chunk size selected to test this experiment was 1MB.

Strategies used The Random Strategy was the only strategy chosen for this experiment.

Considering the example of the file fragmentation with a 100MB file and chunks with 1MB, the multiplication of the file per seeders is as it follows on Figure **4.4**.

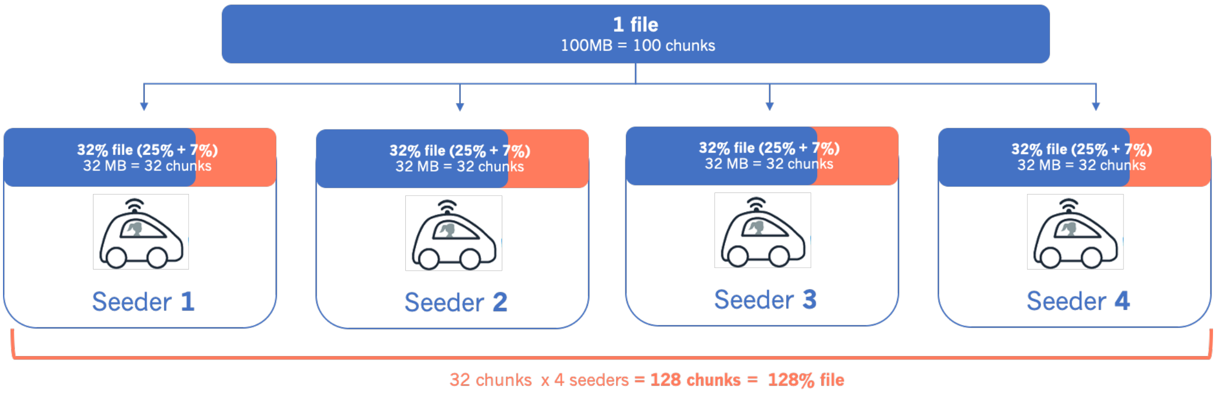


Figure 4.4: File replication amongst seeder vehicles

4.4 Test case description

For a better understanding of the next section of the results, a brief description on key formulas is presented.

To calculate the number of chunks per file it is given that $FS = File\,Size$, $NCF = Number\,of\,Chunks\,per\,File$ and $CS = Chunk\,Size$. Thus:

$$NCF = \frac{FS}{CS} \tag{4.1}$$

and $NCV = Number\,of\,Chunks\,per\,Vehicle$, $PFPS$ (being the percentage of the entire file each seeder gets) and using the NCF value obtained in (4.1), it results that:

$$NCV = \texttt{round}(NCF \times PFPS) \tag{4.2}$$

Then, considering $nseeder$ and NCV from 4.2 , for Experiment 1, it results in:

$$NCV \times nseeder \times CS = constant \tag{4.3}$$

Though for Experiment 2, it results in variable value, since NCV varies because it is higher than the minimum chunks per vehicle needed.

$$NCV \times nseeder \times CS = variable \tag{4.4}$$

Then, the explanation of the results of the offloaded data. Firstly, the seededed percentage corresponds to the percentage fleet-wide of the chunks downloaded from the cloud to the seeders. The offloaded via Wi-Fi percentage corresponds to the chunks shared from the seeders to the leechers. Lastly, the apposteriori is the percentage that represents the amount of chunks that had to be offloaded via cell after the expiration time that allowed the Wi-Fi offload. Thus, the sum of these 3 parameters is as follows on Equation **4.5**.

$$Seeded(\%) + OffloadedV2V(\%) + Apposteriori(\%) = 100\% \tag{4.5}$$

To calculate the average offloaded V2V (%), as well as the minimum and maximum value, the standard deviation was used. So, given that:

$$Sizeofthesample = n \tag{4.6}$$

Thus, the average value equals to:

$$\bar{x} = \frac{\Sigma x}{n} \tag{4.7}$$

Then, the variance is calculated:

$$s^2 = \frac{\sum(x - \bar{x})^2}{n - 1} \tag{4.8}$$

Lastly, and from the variance on Equation **4.8**, the standard deviation based on a sample is calculated. The sample could have the size of 10 or 20, depending on the "rnseed" chosen to test:

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2} \tag{4.9}$$

As the standard deviation is not entirely accurate, the mathematical effect can be solved using the Confidence Interval (CI). Thus, the CI results in a minimum and a maximum value, in this case, for the average V2V Offload (%).

$$CI = \bar{x} \pm z_c \left(\frac{s}{\sqrt{n}} \right) \tag{4.10}$$

Chapter 5

Results

In this chapter, the results obtained are displayed from the application of the methodology described in chapter 4 of this master thesis: the results of E1 and E2 are showcased, followed by a PowerBI dashboard. The entire data retrieved from the simulation can be found in Appendix **E**.

5.1 E1: Impact of file fragmentation amongst seeders

As said in the methodology, Experiment 1 consists in dividing the file, where the sum of the percentages of the file per seeder is equal to 100%, since they complement each other. Therefore, for E1 the percentage of the fleet-wide seeded file is constant, being equal to **0.3%**, both in the test with 100MB and 1GB, only varying the offload and aposteriori rates.

5.1.1 100MB

The experiment 1 of the 100MB file size is the most detailed one regarding the assessment of different variables in this holistic approach of the simulation, considering that different factors contribute to the ideal solution both efficiency and costly wise. So, this subsection starts with a seeding strategy overview, followed by the cost overview. Then, a chunk size comparison is provided as well as a test repetition overview. Lastly, the essence of the findings from Experiment 1 with 100MB file size is displayed.

5.1.1.1 Strategies overview

Random strategy For this seeding strategy, the general tendency of the V2V average offload is to decrease from 1 to 100 seeders. Though, if looking carefully, there is a reason why the first seeders offload rates are high, with a high confidence interval, which can lead to a benefit or wrongdoer for the network. Thus, it is expected that the confidence level decreases as the number of seeders increase. For the nseeder=1, the confidence level is (17.42%), so if the vehicle has good throughput rates as well as a good circulation in the network, the offload can reach the 89.72%. Otherwise, if the vehicle is stationary and not as close as other vehicles, then it can obtain 54.89%. Therefore, the first seeders offload rates depend directly on the activity and quality of the few selected seeder(s). With the increase in the nseeder, the results become more robust (with the interval of confidence shrinking) while the average offload tends to be in the 50% cluster.

Table 5.1: Experiment 1 - Results of random strategy (100MB)

N° of seeders	PFPS	**V2V Average Offload (%)**	Confidence Level (%)	Minimum Offload (%)	Maximum Offload (%)
1	100%	72.31%	17.42%	54.89%	89.72%
2	50%	64.97%	4.52%	60.45%	69.49%
4	25%	57.32%	5.46%	51.87%	62.78%
5	20%	57.48%	4.24%	53.24%	61.72%
10	10%	55.46%	2.30%	53.16%	57.76%
20	5%	56.57%	1.72%	54.85%	58.29%
25	4%	56.60%	1.58%	55.01%	58.18%
50	2%	54.55%	1.26%	53.29%	55.82%
100	1%	55.85%	2.47%	53.38%	58.31%

If analysing the values from the nseeder=10, it is also clear that it is better to have 20 or 25 rather than 50 or 100 vehicles as seeders. So, in a detailed view, the more seeders the mesh possesses do not always assure the best offload. Figure **5.1** represents in blue shadow the confidence interval and in blue line the offload.

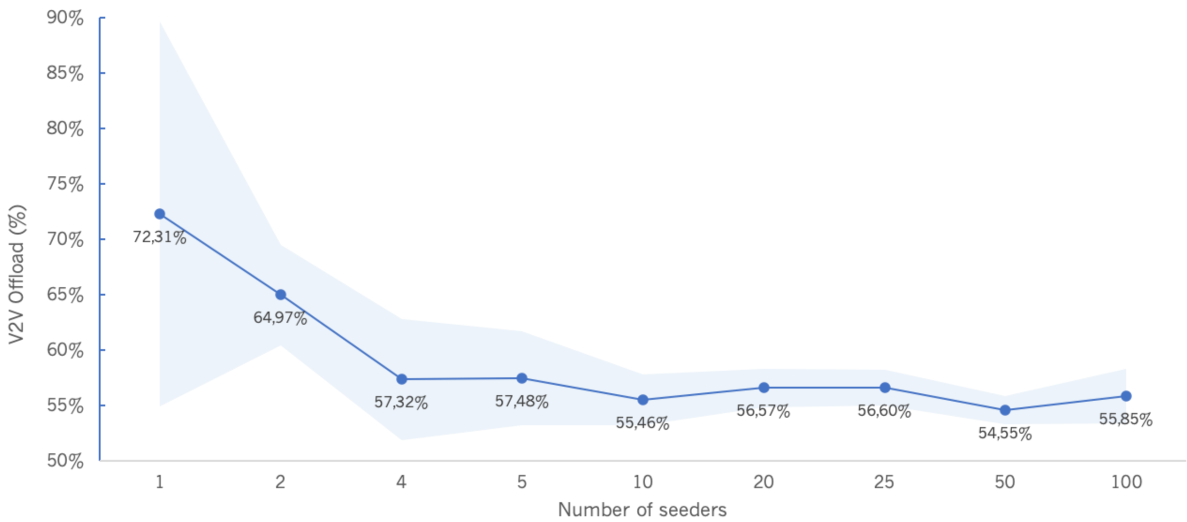


Figure 5.1: V2V Offload (%) of Experiment 1 for 100MB - random strategy

Weighted strategy For this seeding strategy, a similar behavior compared to the random strategy can be overseen. Generally, the less the nseeder, the higher the offload. Though, in contrast with the random strategy, the interval of confidence is reduced in the first values for the nseeder. So, due to the nature of this seeding strategy, the vehicles chosen are the ones with the highest activity in the mesh, leading to better offloads at all times. Hence, in the weighted strategy, it is expected that no "bad seeders" are selected as first seeders.

Even though this strategy is the ideal scenario for the simulation, it is highly difficult to predict in the real world. Thus, the reality constraint brings additional pain to the actual and legitimate behavior of the mesh network.

Table 5.2: Experiment 1 - Results of weighted strategy (100MB)

Nº of seeders	PFPS	**V2V Average Offload (%)**	Confidence Level (%)	Minimum Offload (%)	Maximum Offload (%)
1	100%	86.87%	0.64%	86.23%	87.51%
2	50%	66.43%	3.06%	63.37%	69.49%
4	25%	61.22%	1.67%	59.55%	62.89%
5	20%	60.09%	1.83%	58.27%	61.92%
10	10%	59.35%	2.65%	56.70%	62.00%
20	5%	59.15%	1.69%	57.46%	60.84%
25	4%	58.65%	1.50%	57.15%	60.15%
50	2%	56.30%	0.83%	55.47%	57.13%
100	1%	56.99%	2.26%	54.73%	59.25%

In Figure **5.2**, the orange shadow represents the confidence interval, and the gray line the V2V offload.

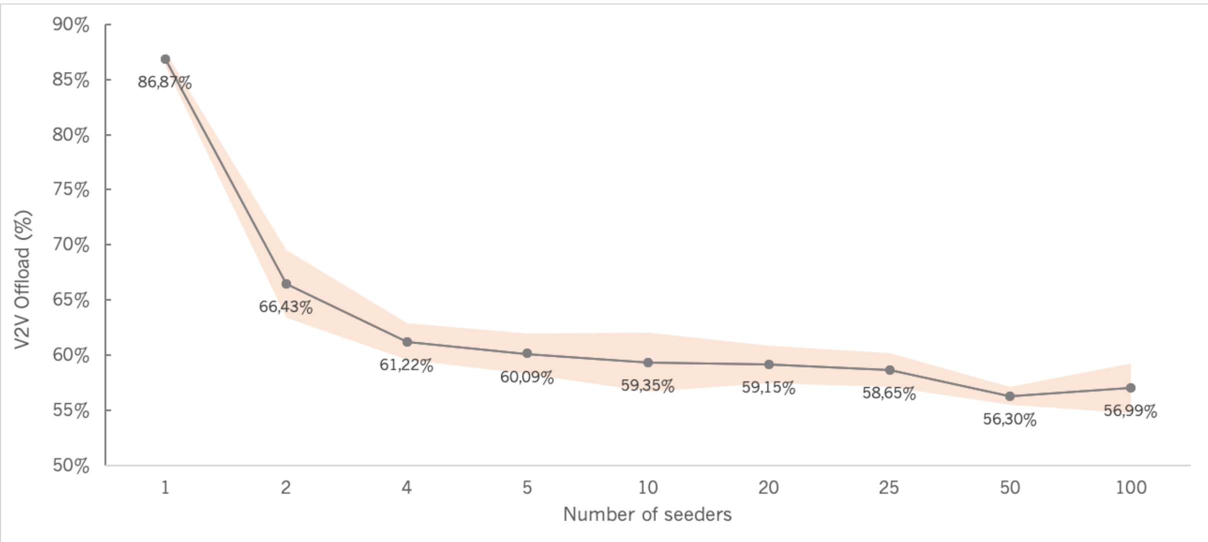


Figure 5.2: V2V Offload (%) of Experiment 1 for 100MB - weighted strategy

First Come First Served (FCFS) For this strategy, the first (out of the 356 vehicles) to ignite in the mesh are the ones selected as seeders, independently of their performance or activity in the network. The behavior of the mesh does not change no matter how many times it is run (10' or 20' in this case), since the dataset has those pre-configurations established. So, for example with nseeder=1, the offload is 86.41%, meaning that a good vehicle was by chance selected. Though, when having 2 nseeder, the offload drops down to 45.65%, meaning that one of the two vehicles is not as engaged in the network as the other one. Due to the nature of this strategy, it does not make sense to estimate the confidence interval.

Nº of seeders	PFPS	**V2V Offload (%)**
1	100%	86.41%
2	50%	45.65%
4	25%	53.48%
5	20%	54.16%
10	10%	55.18%
20	5%	57.41%
25	4%	57.67%
50	2%	55.51%
100	1%	56.86%

Table 5.3: Experiment 1 - Results of FCFS strategy (100MB)

In the following Figure **5.3**, the gray line represents the V2V offload (%) per nseeder. The nature of this strategy is dependent on the first vehicles to ignite, so it does not represent a real case scenario.

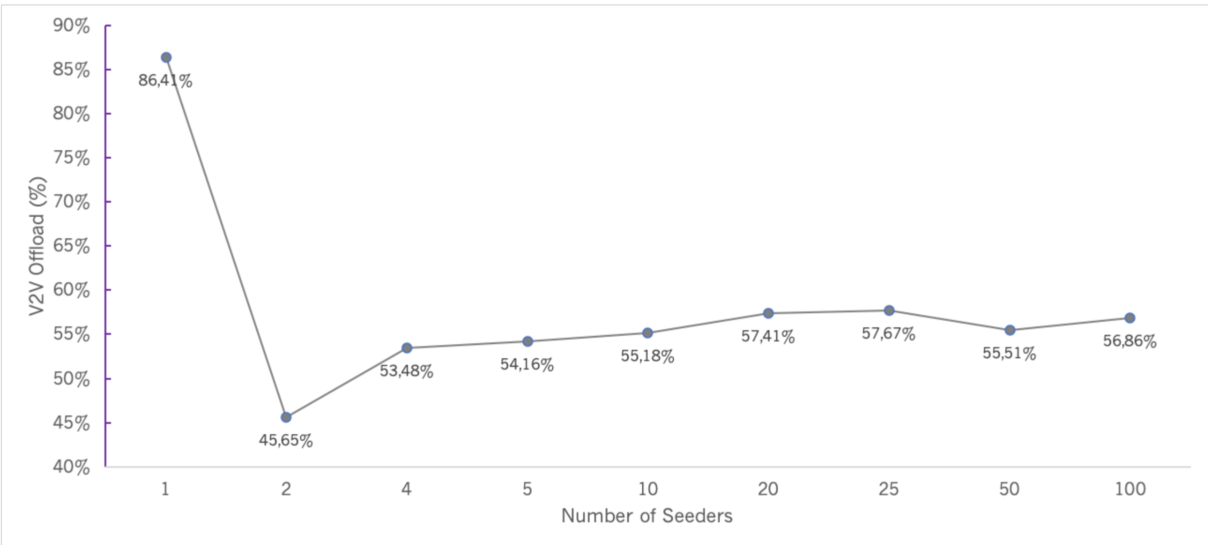


Figure 5.3: V2V Offload (%) of Experiment 1 for 100MB - FCFS strategy

5.1.1.2 Cost overview

In order to approximate the offload values the closest to reality, the Random Strategy is used for the costs overview. The cell price considered to do the simulation results was 0.07€/MB, considering the price reviewed in the cell price analysis practiced in Portugal. This value varies from country to country, as shown in the critical analysis. If the OEMs needed to offload 100MB through a mesh of 356 vehicles, only using the current solutions of cell connection, the company would need to invest **2492€** in one day only. As explained in the Financial Analysis subsection **3.4.5**, the offload done through V2V Wi-Fi Veniam solution represents savings to the OEMs. With this simulation, specific values for the nseeders were used as a starting ground, and no continuum of values was explored.

Table 5.4: Cost overview for the file fragmentation of a 100MB file

Nº of seeders	PFPS	**V2V Average Offload (%)**	Daily Savings (€)	Daily Expenditure(€)
1	100%	72.31%	+1801,87€	-690,13 €
2	50%	64.97%	+1619,03€	-872,97€
4	25%	57.32%	+1428,51€	-1063,49€
5	20%	57.48%	+1432,38 €	-1059,62€
10	10%	55.46%	+1382,06€	-1109,94€
20	5%	56.57%	+1409,7€	-1082,3€
25	4%	56.60%	+1410,37€	-1081,63€
50	2%	54.55%	+1359,41€	-1132,59€
100	1%	55.85%	+1391,68€	-1100,32€

Figure 5.4: Optimistic, realistic and pessimistic cost view for the file fragmentation of a 100MB file

Optimistic View Represents the best-case scenario for the dataset, where the offload is maximum and therefore the savings are maximum. Here, nseeder=1 is the ideal value with an average of 72.31%, with savings of 1801.87€daily.

Realistic View Represents the most identical to reality scenario, where the average offload is not maximum and not the minimum, but the maximum after the initial nseeder. Here, nnseeder=20 or nseeder=25 are the ideal values, representing an average offload of 56%, with savings of 1410€daily.

Pessimistic View Represents the worst-case scenario, where the average offload is the minimum. Here, nseeder=50 represents an average offload of 54.55% with savings of 1359.41€daily.

The current testbed represents the behavior of one entire day and thus it can not be generalised for the following days. Though, it is likely that for the same region and vehicle density, the behavior is approximate to the one currently analysed. So, if the behavior would be exactly the same as the one tested, then the approximate savings to the OEMs would be:

- One day: 1.410 €
- One week (7 days): 9.870 €
- One month (30 days):42.300 €
- One year (365 days): 514.650 €

As said, it is not certain that the behavior is the same as the day tested, but if similar, the results would be the ones stated above. Though, the behavior of additional days is a key point of interest and it will be highlighted as future work.

5.1.1.3 Chunk size comparison

To understand if the chunk size had an effect in the offload result, chunk sizes with 1MB, 5MB, and 10MB were tested for the 100MB file dissemination, for 1, 2, and 4 seeders for the 3 different strategies as seen in Figure **5.5**.

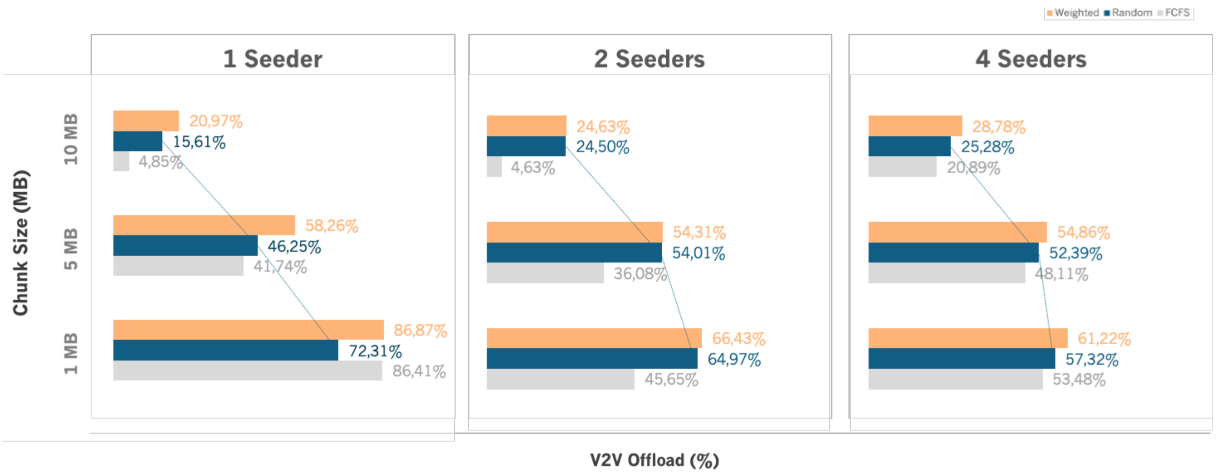


Figure 5.5: Chunk size comparison (1MB, 5MB and 10MB) for 100MB File for 1, 2 and 4 seeders

Even though this is not an optimization function stating the exact right size of the chunk, it provides general insight on either if smaller (1MB), medium (5MB) or bigger (10MB) sized chunks work the best. The Random Strategy (in blue) is used as a reference for growth tendency comparison. Starting with the analysis of the test with 1 seeder, it is possible to oversee that the offload is increasing from the 10MB chunk to the 5MB chunk, and from 5MB to 1MB chunk. The same behavior occurs for 2 and 4 seeders. Though, the offload growth from one chunk size to another is distinct depending on the seeders' number.

The growth of V2V offload in 1 seeder is nearly constant. Though, for both 2 and 4 seeders, the growth from 10MB to 5MB chunk is nearly the same as with the 1 seeder. Yet, there is a lower degree growth from 5MB to 1MB, which is more pronounced in the 4 seeders case when compared with the 2 seeders. This represents that the more the seeders, the tendency is to approximate the results of 5MB to 1MB results.

Also, for a matter of example, in the case of the 4 seeders, each vehicle gets 25% of the file, corresponding to 25 MB. Thus, if the chunk is 10MB, then each seeder will actually only send 2 chunks, corresponding to 20MB, since it cannot send half of a chunk of 5MB alone, translating to an incomplete chunk offload, and consequently a bad offload rate.

Overall, in all strategies, the minor the chunk size, the higher the V2V offload (%). The casual explanation for this behavior collides with the time of connection required to send the specified amount of chunks.

Considering the scenario of two vehicles moving with a throughput of 1MB/second and the TTFB of 3 seconds. Then, if two cars are connected 5 seconds, then around 2 seconds are spent on sending the data. If using 1MB chunks, then 2 chunks are transferred from one vehicle to the other. If using 5MB or 10MB chunk, then the chunks are not transferred from one vehicle to the other. Thus, for a scenario where vehicles are connected 15 seconds, then the transference could happen. Since the connections are complex and usually few seconds or even milliseconds (Figure **4.1**), the chance of connection and offloading a chunk increases when having a small-sized chunk. Consequently, the bigger the chunk the more time it requires to send to the other vehicle, that most of the time might not be available due to the TTFB, resulting in a fail chunk send. Albeit the offload percentages tend to approximate with the 5MB to 1MB chunks, the chunk of 1MB was chosen for the following experiments due to its constant superiority in matters of timing adaptability to send the chunks, together with the performance to offload data in relation to the other chunk sizes. Sizes less than 1MB were not explored, since they would add granularity and noise complexity around the results. Thus, together with the research done on chunks between 1MB to 5MB adds the interest in finding if chunks less than 1MB would be ideal. These proposals for the chunk size are a topic to be highlighted in the future work to be developed in chapter 6.

5.1.1.4 Test repetition overview

As stated before, to understand the impact of iterating each test with the same parameters, each test for this first Experiment and for the 100MB file size was run 10 and 20 times. The 10 repetitions results were despicable in the previous subchapter. In this subchapter it's introduced the results of the 20 repetitions, resulting in a comparison between these two conjectures.Similarly to the variation in the chunk size, the repetition impact in not an optimization function that determines the most accurate number of repetitions. Yet, it shows the impact on the overall behavior if testing less or more times.

For the random strategy (Figure **5.6**), the yellow shadow represents the new confidence interval with 20', compared with the dotted grey line that stands for the confidence levels of 10'. Thus, regarding the confidence interval/levels one can adjudge that the more the repetitions, the stricter the confidence which providing more concise intervals/levels. In the blue line, it's represented the 20' offload, whereas in the gray line the 10' offload is showcased. Here the values for the average offload (%) are undoubtedly close to each other when comparing 10' with 20'. Thus, even though the confidence is more precise, the average values do not change much of their behavior.

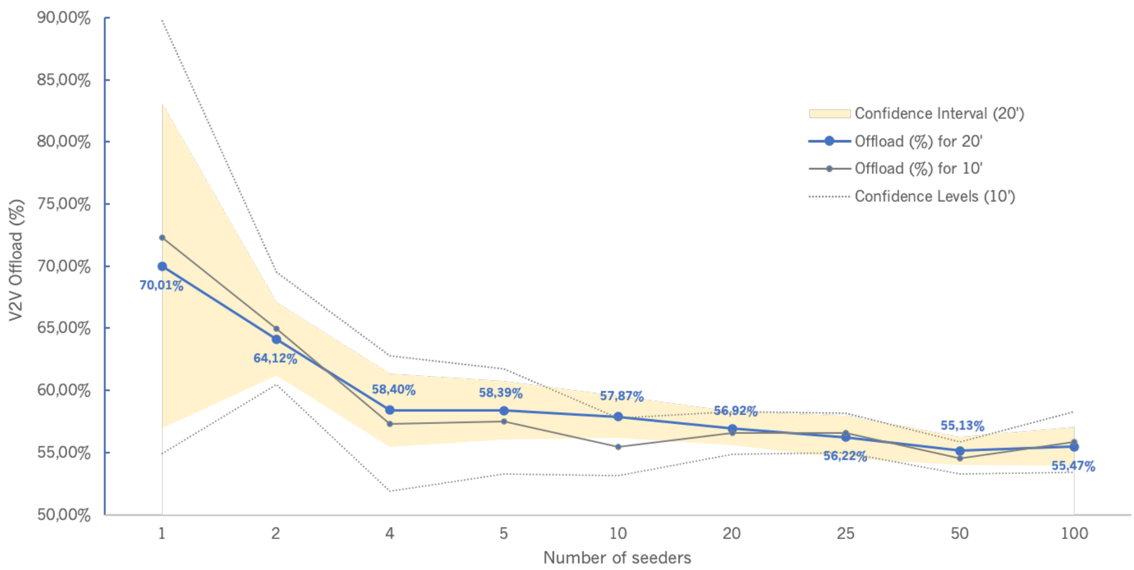


Figure 5.6: Comparison of V2V Offload (%) of Experiment 1 (100MB) with 10 and 20 repetitions for the random strategy

For the weighted strategy (Figure **5.7**), the same behavior happens when compared to the random strategy: From 10' to 20' the confidence becomes stricter, but the average values do not change much their behavior. Nevertheless, there is the exception when nseeder=1, where both the average value and confidence interval are distinct. This factor is caused by the nature of the strategy, which chooses vehicles depending on their activity. So, when increasing the number of iterations, it is expected that the one vehicle chosen to be seeder is worse. While with 10' repetitions the simulation captures each time one high-quality vehicle that is able to distribute its chunks seamlessly, with 20' it can capture vehicles that do not communicate as effectively.

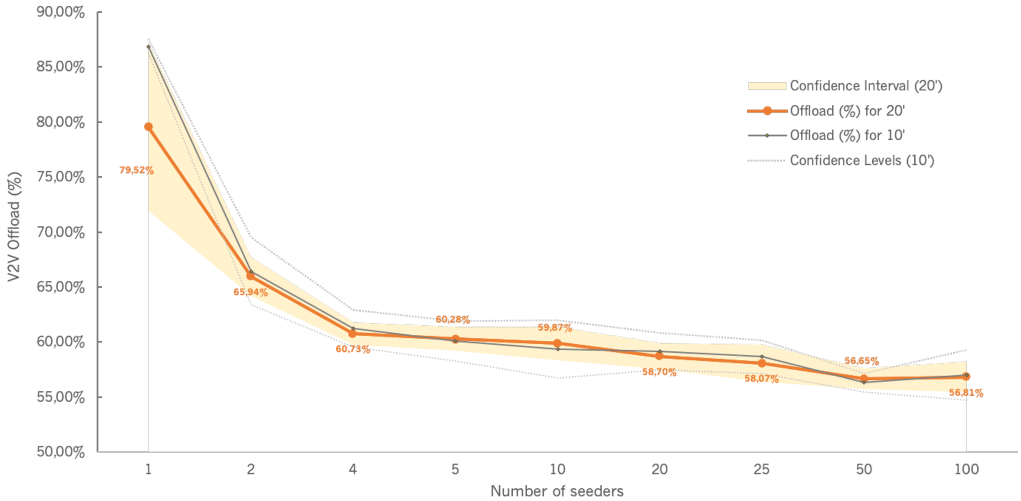


Figure 5.7: Comparison of V2V Offload (%) of Experiment 1 (100MB) with 10 and 20 repetitions for the weighted strategy

For the First Come First Served (FCFS) strategy (Figure **5.8**), as explained before, the nature of the strategy does not require the study of the confidence intervals, because it is dependent on the dataset available. Due to that, the offload does not vary significantly with more iterations.

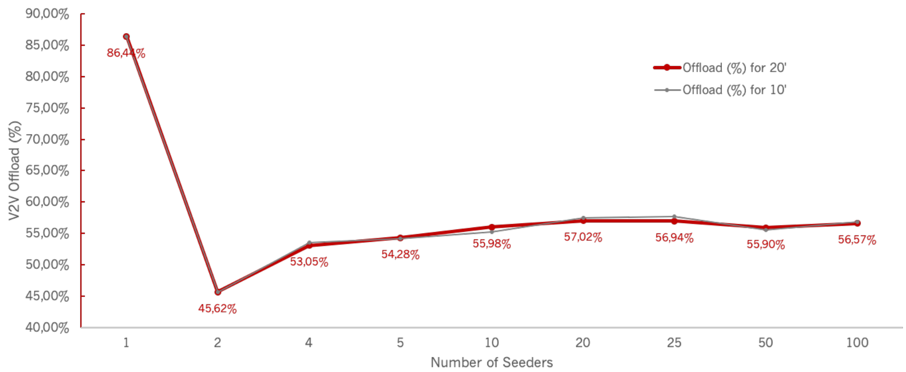


Figure 5.8: Comparison of V2V Offload (%) of Experiment 1 (100MB) with 10 and 20 repetitions for the FCFS strategy

5.1.1.5 Conclusion on 100MB file fragmentation

Strategy overview The general tendency of the strategies is to decrease the offload as the nseeder increases.

Random Generally the offload values are decreasing as the nseeder increase. Though, if analysing in detail, the Confidence Intervals are at its highest when the nseeder are low. Thus, three perspectives emerged: the optimistic (the best-case scenario with the higher offload), the realistic (after considering the confidence intervals to the initial seeders, the nseeder with maximum offload) and the pessimistic (the worst-case scenario with the lowest offload). The realistic view presumes that the ideal nseeder is at nseeder=25, with the highest after the initial nseeder.

Weighted Ideal strategy for the simulation due to the ranking of seeders being dependent on their activity. Yet, highly challenging to recreate in real-world. No "bad seeders" are selected. After the nseeder=1, the next best case number of seeders is at nseeder=2.

FCFS Strategy that is dependent on the vehicles that ignite first and to the current dataset. Thereupon, if one selected seeder is in a bad state, the offload is worse than if it was in a good state. After the nseeder=1, the next best-case number of seeders is at nseeder=25.

All of the three strategies will be tested as well for the 1GB file size to understand its behavior.

Figure **5.9** compares the behavior of the three strategies for the 100MB file. From nseeder=1 to nseeder=20 inclusive the behavior of the 3 strategies varies. Though from nseeder=20 to nseeder=100 the behaviors tend to become similar.

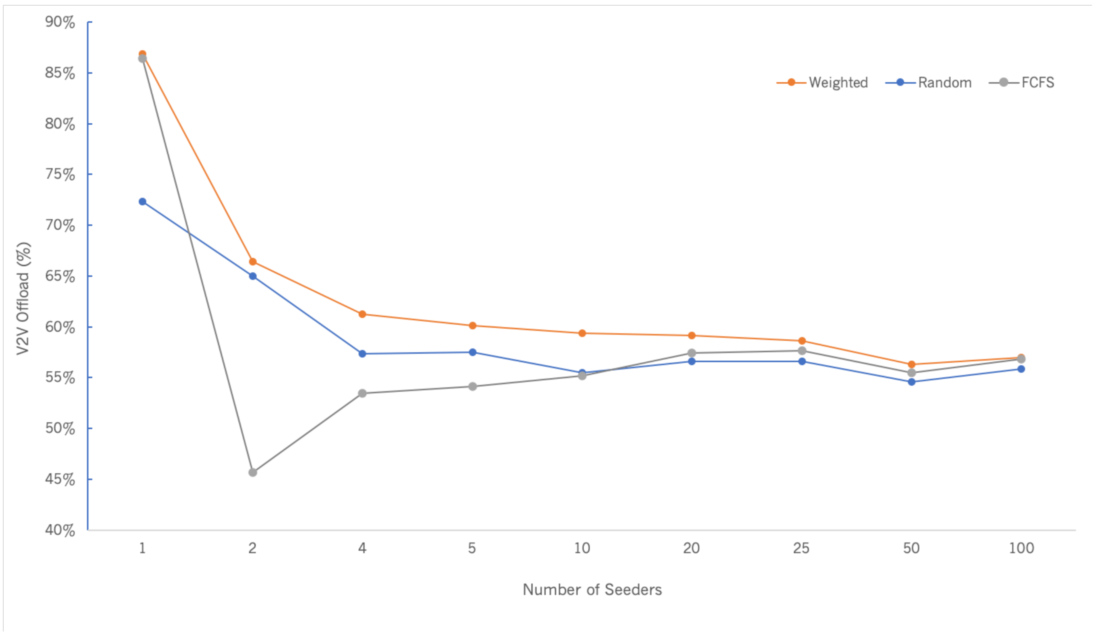


Figure 5.9: V2V Offload (%) of 100MB file fragmentation per seeding strategy

Figure **5.10** represents the same content as Figure **5.9**, but with a proportional x-axis, giving a clear idea of the differences of having more or fewer seeders in the three strategies.

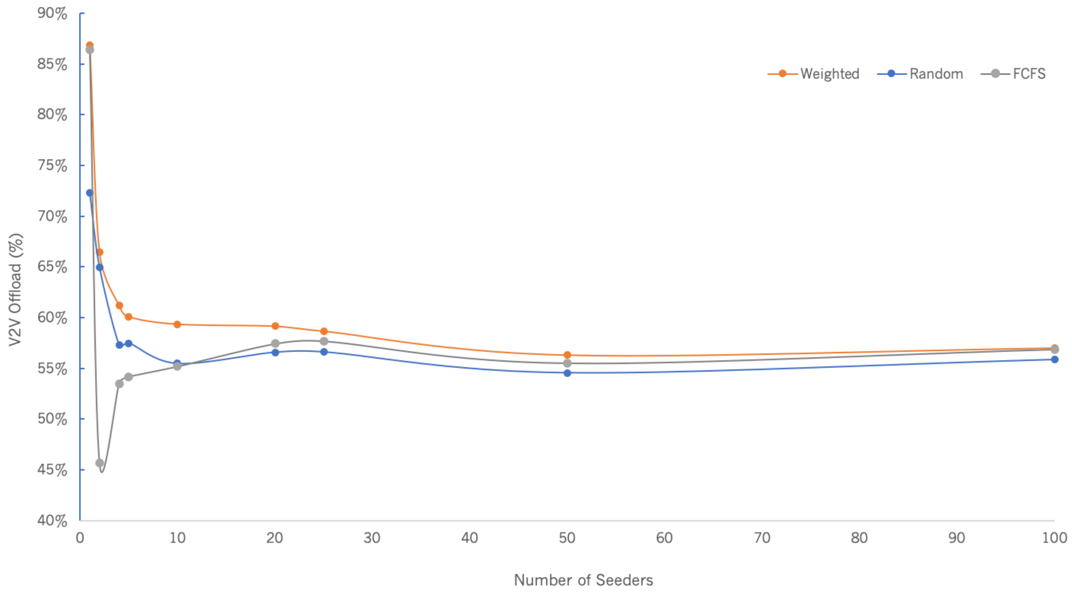


Figure 5.10: V2V Offload (%) of 100MB file fragmentation per seeding strategy (Proportional View)

Cost Overview Using the random strategy as the closest to reality one, the worst-case scenario using Veniam software indicates a total of savings of 1.360€(around 55%), while the best-case scenario indicates 1.802€(around 72%) to the OEMs.

Chunk Size Comparison Different chunk sizes were tested (1MB, 5MB, and 10MB). The option that led to more significant values of offload (ignoring the time factor) was the 1MB chunk, that was used for Experiment 1 and will be used for Experiment 2. A suggestion of future work can be seen in subchapter of future proposed work in chapter 6.

Test Repetition Overview The tests were repeated 10 and 20 times separately. Overall, the average V2V offload (%) did not change its behavior when repeating the test more times. Therefore, the results from the 10 times were used for Experiment 1 and will be also used for E2.

5.1.2 1GB File

For the 1GB file, the seeding strategies and cost overview are detailed.

5.1.2.1 Strategies overview

Random In contrast with the 100MB file, the 1GB file presents growth in the V2V offload as the nseeder increase. Similarly, the confidence interval narrows to a steady value. Generally, the more nseeder, the better the offload rate (in this case, when nseeder=250, the offload=28.20%).

Table 5.5: Experiment 1 - Results of random strategy (1GB)

N° of seeders	PFPS	V2V Average Offload (%)	Confidence Level (%)	Minimum Offload (%)	Maximum Offload (%)
1	100%	12.67%	4.02%	8.66%	16.69%
2	50%	19.28%	1.80%	17.48%	21.09%
4	25%	22.29%	1.03%	21.25%	23.32%
5	20%	23.59%	0.80%	22.79%	24.40%
8	12.5%	24.65%	0.73%	23.92%	25.38%
10	10%	24.98%	0.63%	24.35%	25.61%
20	5%	26.21%	0.36%	25.85%	26.57%
25	4%	26.46%	0.28%	26.18%	26.75%
40	2.5%	27.02%	0.17%	26.85%	27.19%
50	2%	27.19%	0.10%	27.09%	27.29%
100	1%	27.76%	0.07%	27.68%	27.83%
125	0.8%	27.87%	0.07%	27.80%	27.95%
200	0.5%	28.10%	0.03%	28.07%	28.13%
250	0.4%	28.20%	0.04%	28.17%	28.24%

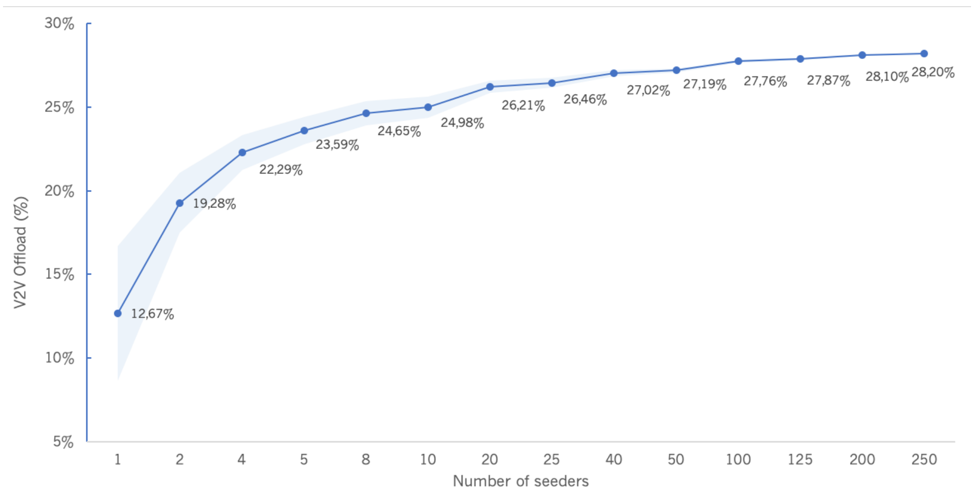


Figure 5.11: V2V Offload (%) of Experiment 1 for 1GB - random strategy

Weighted The behavior of the V2V offload in the weighted is similar to the random strategy (even though each individual value is higher). Thus, the V2V offload increases, and the confidence interval narrows to a steady value as the nseeder increments. Generally, the more nseeder, the better the offload rate (in this case, when nseeder=250, the offload=28.53%)

Table 5.6: Experiment 1 - Results of weighted strategy (1GB)

Nº of seeders	PFPS	V2V Average Offload (%)	Confidence Level (%)	Minimum Offload (%)	Maximum Offload (%)
1	100%	17.02%	1.28%	15.74%	18.30%
2	50%	20.11%	1.13%	18.97%	21.24%
4	25%	23.46%	0.57%	22.89%	24.03%
5	20%	24.06%	0.40%	23.66%	24.46%
8	12.5%	25.50%	0.22%	25.28%	25.73%
10	10%	25.98%	0.17%	25.80%	26.15%
20	5%	26.85%	0.17%	26.67%	27.02%
25	4%	27.01%	0.17%	26.85%	27.18%
40	2.5%	27.54%	0.11%	27.43%	27.65%
50	2%	27.69%	0.13%	27.56%	27.82%
100	1%	28.13%	0.08%	28.06%	28.21%
125	0.8%	28.25%	0.06%	28.19%	28.31%
200	0.5%	28.49%	0.03%	28.46%	28.52%
250	0.4%	28.53%	0.04%	28.48%	28.57%

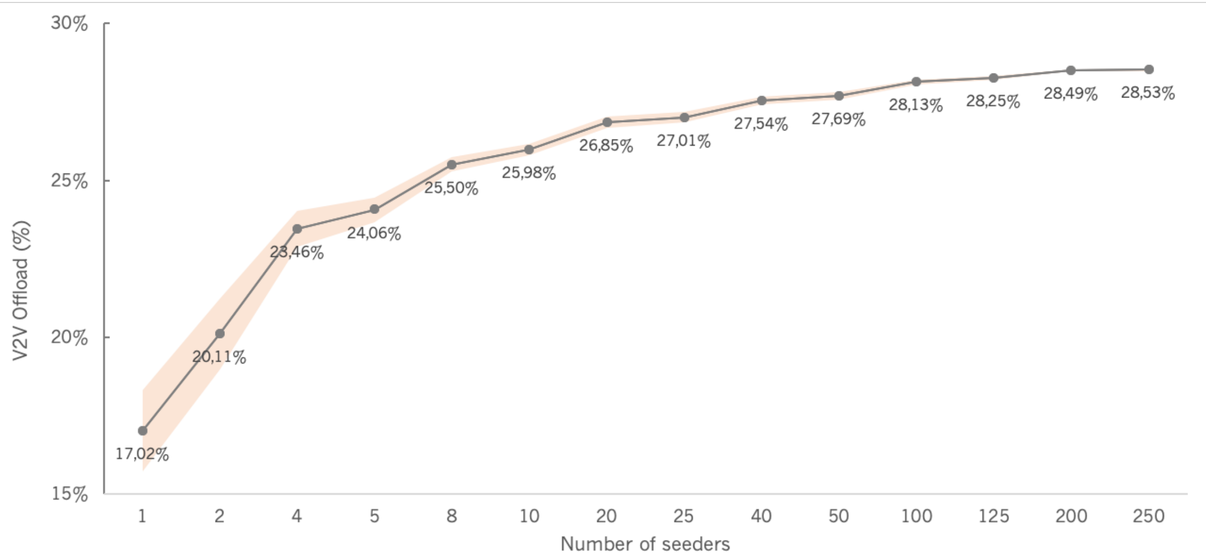


Figure 5.12: V2V Offload (%) of Experiment 1 for 1GB - weighted strategy

FCFS The behavior of the V2V offload in the FCFS is similar to the previous strategies, excluding the confidence interval due to the strategy nature. Though, the behavior that happened with the 100MB file happens again with the 1GB file when only 2 seeders are selected: most likely, the second seeder chosen is a low-quality seeder, impacting the general offload rate. Generally, the more nseeder, the better the offload rate (in this case, when nseeder=250, the offload=28.68%).

Table 5.7: Experiment 1 - Results of FCFS strategy (1GB)

N° of seeders	PFPS	**V2V Offload (%)**
1	100%	13.62%
2	50%	13.37%
4	25%	21.37%
5	20%	23.92%
8	12.5%	24.48%
10	10%	25.12%
20	5%	26.52%
25	4%	26.66%
40	2.5%	27.40%
50	2%	27.65%
100	1%	28.25%
125	0.8%	28.42%
200	0.5%	28.65%
250	0.4%	28.68%

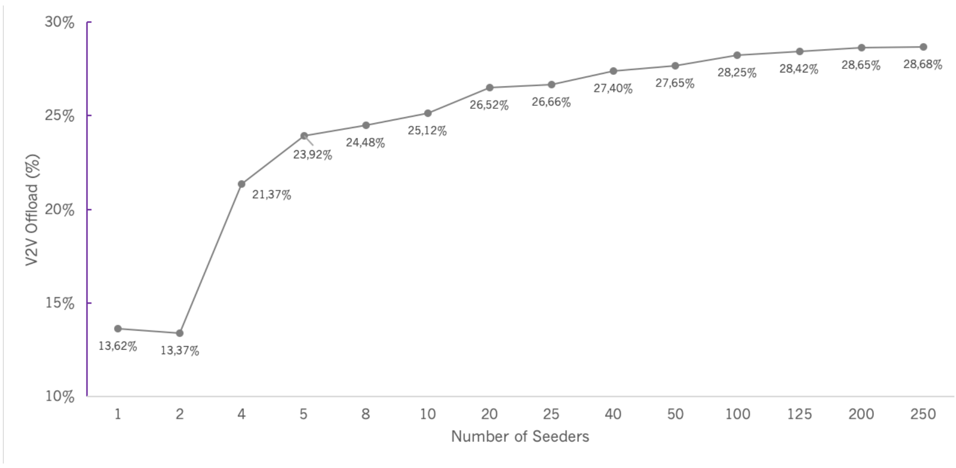


Figure 5.13: V2V Offload (%) of Experiment 1 for 1GB - FCFS strategy

5.1.2.2 Cost overview

Similarly to the previous test with 100MB, the random strategy is used to approximate the results of the maximum to reality. Then, using the same price per MB (0.07 €), if the OEMs need to offload 1GB though a mesh of 356 vehicles, only using cell connection solutions, the company would need to invest **24920€** in one day only. Using V2V Wi-Fi Veniam solution the OEMs are already saving as seen in Table **5.8**. In contrast with the 100MB file, in this case (1GB) there are no optimistic, realistic, or pessimistic views, since there are no significant variations on the behavior. In this case, the values of the offload are always increasing. The ideal nseeder=250, with an average offload of 28,20%, representing a total saving of **7028.19€** in one day only.

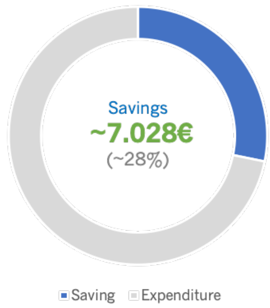


Figure 5.14: Cost view for file fragmentation of a 1GB File

Table 5.8: Cost overview for the file fragmentation of a 1GB file

N° of seeders	PFPS	V2V Average Offload (%)	Daily Savings (€)	Daily Expenditure(€)
1	100%	12.67%	+3157.86€	-21762.14€
2	50%	19.28%	+4804.83€	-20115.17€
4	25%	22.29%	+5553.42€	-19366.58€
5	20%	23.59%	+5879.13€	-19040.87€
8	12.5%	24.65%	+6143.78€	-18776.22€
10	10%	24.98%	+6224.77€	-18695.23€
20	5%	26.21%	+6531.28€	-18388.72€
25	4%	26.46%	+6594.83€	-18325.17€
40	2.5%	27.02%	+6733.13€	-18186.87€
50	2%	27.19%	+6775.75€	-18144.25€
100	1%	27.76%	+6916.80€	-18003.20€
125	0.8%	27.87%	+6946.20€	-17973.80€
200	0.5%	28.10%	+7001.77€	-17918.23€
250	0.4%	28.20%	+7028.19€	-17891.81€

5.1.2.3 Conclusion on 1GB file fragmentation

The behavior of the three strategies for this experiment with the file size of 1GB is similar, standing out that the more the nseeder, the better the offload (%). Even though there are more nseeder in the mesh with this solution and as it is considered the better option, the seeded percentage fleet-wide remains the same (equals to 0.3%).

Therefore, albeit the file is divided into more chunks and shared through more seeders, the price expended in cell remains the same as with 1 seeder, since what influences is the size of the file and not to how many vehicles the chunks go to.

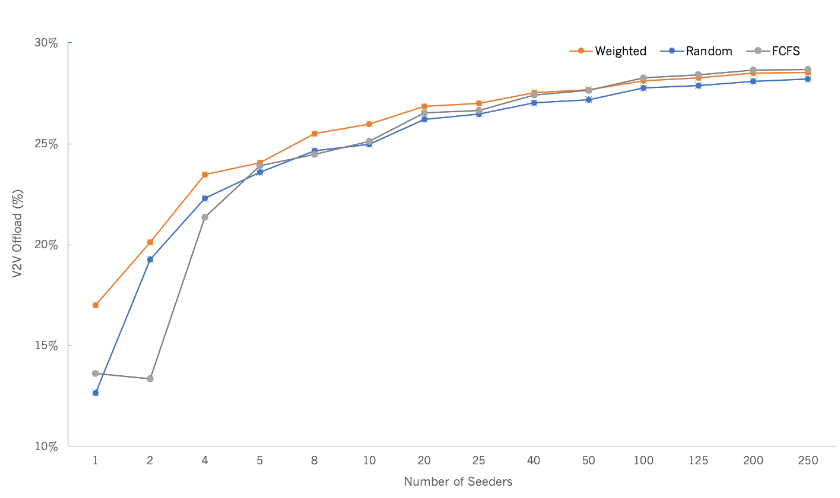


Figure 5.15: V2V Offload (%) of 1GB file fragmentation per seeding strategy

Thus, this is also a topic to be highlighted in the future work chapter, since it would be interesting to determine the compromise between having fewer chunks per vehicle but the same seeded percentage fleet-wide. Thus, in Figure **5.16** (the proportional view) it is possible to understand that the offload grows until a certain point to become stable. Therefore, if there is actually a cost impact due to having more nseeder in the network, the ideal solution is no longer nseeder=250. Yet, the minimum nseeder of when the offload starts to stabilize. Hence, nseeder=20 or nseeder=25 would be a good compromise between costs and offload rate. The savings calculated in **5.1.2.2** only assume that the price is the same either sharing the file through 1 or 250 seeders, and do not take into consideration the aspect of additional cost if having more seeders.

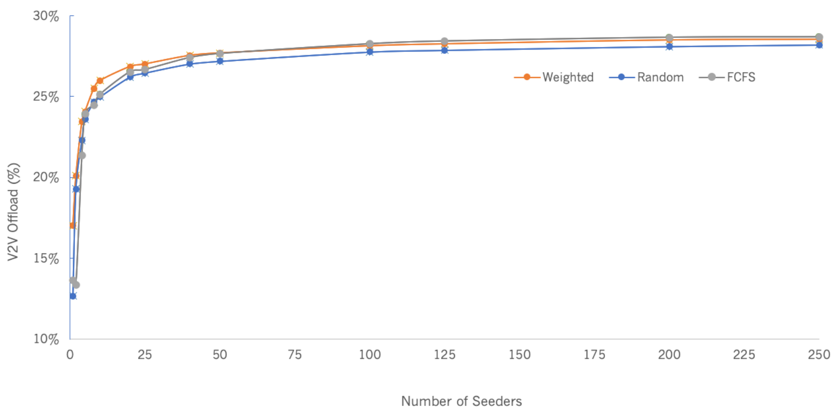


Figure 5.16: V2V Offload (%) of 1GB file fragmentation per seeding strategy - proportional view

5.1.3 Overall reflection on file fragmentation experiment (E1)

This subsection is a compilation and comparison of the entire experiment 1, which consisted of analysing the impact in the network of the fragmentation of a file amongst seeder vehicles. The tests were carried both with 100MB and 1GB file sizes, and Figure **5.17** showcases the behavior of the random strategies with both file sizes for this first experiment.

At first sight, it is clear that the growth linear trendline is opposite when comparing both sizes. So, on one hand, for the 100MB file size (in yellow) the tendency reveals that the more the nseeder, the less the offload. On the other hand, for the 1GB file size (in green) the tendency reveals that the more the nseeder, the higher the offload.

In the graph, it is also highlighted that there is a big gap between offload rates when comparing both sizes. For instance, when nseeder=5, for the 100MB the offload is 57.48%, whereas in the 1GB it is 23.59%.

Thus, the financial impact (percentage-wise) is bigger when offloading files with minor sizes.

Both these conclusions are generalist, but provide a clear overview of the impact of the file size in the offload rate when fragmenting the file amongst the seeders.

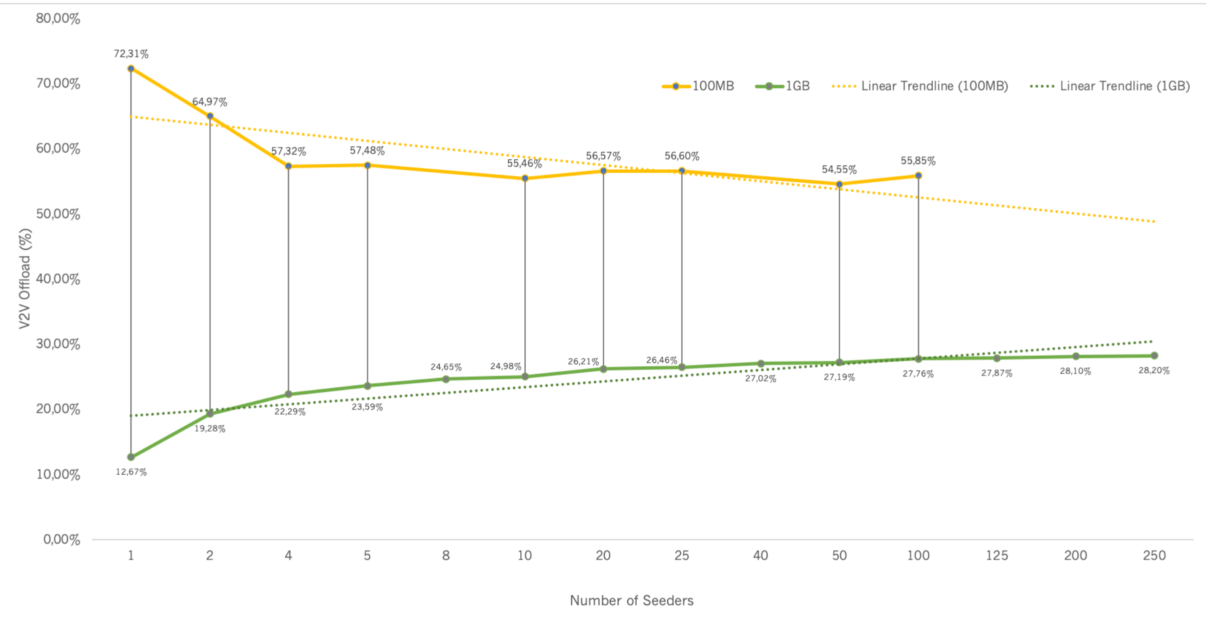


Figure 5.17: Comparison of the V2V offload (%) of the file fragmentation of the 100MB and 1GB file

Table **5.9** showcases the summarised findings of E1 for both file sizes.

Table 5.9: Highlights of Experiment 1 - File fragmentation amongst seeder vehicles

Measure	**Description**
Seeding Strategies	Both the 100MB and 1GB file sizes were tested with Random, Weighted, and FCFS strategies. The one used to extract clear results was the Random, since it is the behavior that is the most approximate to reality.
Cost Overview	The impact percentage-wise in the savings is higher in the 100MB file (around 57%, which corresponds to 1.410€) when compared with 1GB file size (around 28%, which corresponds to around 7.028€). Though, the utilisation of Veniam software translates in savings to the OEMs, even for pessimistic scenarios.
Offload Rate (%)	In the 100MB the offload rates are higher when compared to the 1GB, due to the time needed to connect to offload the file (more times needed to offload a bigger size).
Offload Growth(%)	The tendency in 100MB file is to decrease the offload as the nseeder increase, whereas in the 1GB file the tendecy is to increase the offload as the nseeder increase.

5.2 E2: Impact of file replication amongst seeders

As explained in the methodology, experiment 2 (E2) details the replication of chunks of the file amongst the seeders of the mesh network containing 356 vehicles. Therefore, the sum of total PFPS is bigger than 100%, since there are repeated chunks in the network. So, in contrast with the previous experiment, the seeded percentage fleet-wide is no longer 0.3%, but it is varying. Hence, in E2, all of the seeded, offloaded and aposteriori percentages change.

The E2 is an upgrade test of the E1, since it adds incrementally seeded percentage, from the ground base of 0.3%. Though, this experiment adds redundancy to the file in the network, since some of the chunks are repeated. Only Random Strategy, 1MB chunks, and 10 repetitions were used in E2.

5.2.1 100MB File

Table **5.10** displays the offload (in bold) and confidence level (in brackets) per seeder and per PFPS. In green shadow it is highlighted the best option per nseeder.

Table 5.10: Results of Experiment 2 - File replication amongst seeders (100MB)

Percentage of file per seeder →

Number of Seeders ↓

	1%	2%	4%	8%	16%	32%	64%	100%
1								**72,31%** (17,42%)
2							**74,64%** (4,01%)	**87,60%** (0,75%)
4						**65,52%** (5,30%)	**85,04%** (2,21%)	**87,89%** (0,28%)
5						**73,15%** (4,22%)	**87,42%** (0,39%)	**87,86%** (0,29%)
10					**72,17%** (2,02%)	**85,78%** (1,13%)	**87,89%** (0,19%)	**87,02%** (0,25%)
20				**71,92%** (2,56%)	**85,14%** (1,00%)	**88,02%** (0,16%)	**86,46%** (0,24%)	**84,61%** (0,31%)
25			**56,60%** (1,58%)	**76,75%** (2,07%)	**86,69%** (0,80%)	**87,72%** (0,12%)	**85,75%** (0,19%)	**83,46%** (0,26%)
50		**54,55%** (1,26%)	**77,46%** (1,33%)	**86,78%** (0,87%)	**87,96%** (0,07%)	**86,28%** (0,42%)	**82,10%** (0,19%)	**77,46%** (0,28%)
100	**55,85%** (2,47%)	**75,46%** (2,36%)	**86,84%** (0,62%)	**87,75%** (0,28%)	**86,26%** (0,07%)	**82,36%** (0,11%)	**74,28%** (0,18%)	**64,87%** (0,27%)

From the Table **5.10**, it is plausible to understand that at the pace the nseeder increase, the PFPS needed to obtain the highest offload is decreasing. Figure **5.18** highlights the growth of offload per file per seeder for each nseeder. For 1 seeder, there is only the option of having 100% of the file, since it is the minimum percentage that a seeder can have. Then, the offload is 72.31%.

In the case of 2 seeders, the minimum PFPS is 50%. So, it was tested for 64% and 100% percentages of the file. The result indicates that the ideal offload is 87.60%, obtained at PFPS = 100%.

For the 4 seeders, the minimum PFPS is 25%, so for that nseeder it was tested for the 32%, 64%, and 100%. The result indicates that the ideal offload is 87.89%, obtained at PFPS = 100%.

For 5 seeders,the minimum PFPS is 20%, so for that nseeder it was tested with 32%, 64% and 100% of the file per seeder. The result indicates that the ideal offload is 87.86%, at PFPS = 100%.

The 10 seeders' results are the turning point in what concerns having 100% of the file always as the best option. As seen, the minimum PFPS is 10%, so it was tested with 16%, 32%, 64%, and 100%. The result indicates that the highest offload (87.89%) is obtained at PFPS as 64%.

For 20 seeders,the minimum PFPS is 5%, so for that nseeder it was tested with 8%, 16%, 32%, 64% and 100% of the file per seeder. The result indicates that the ideal offload is 88.02%, at PFPS = 32%.

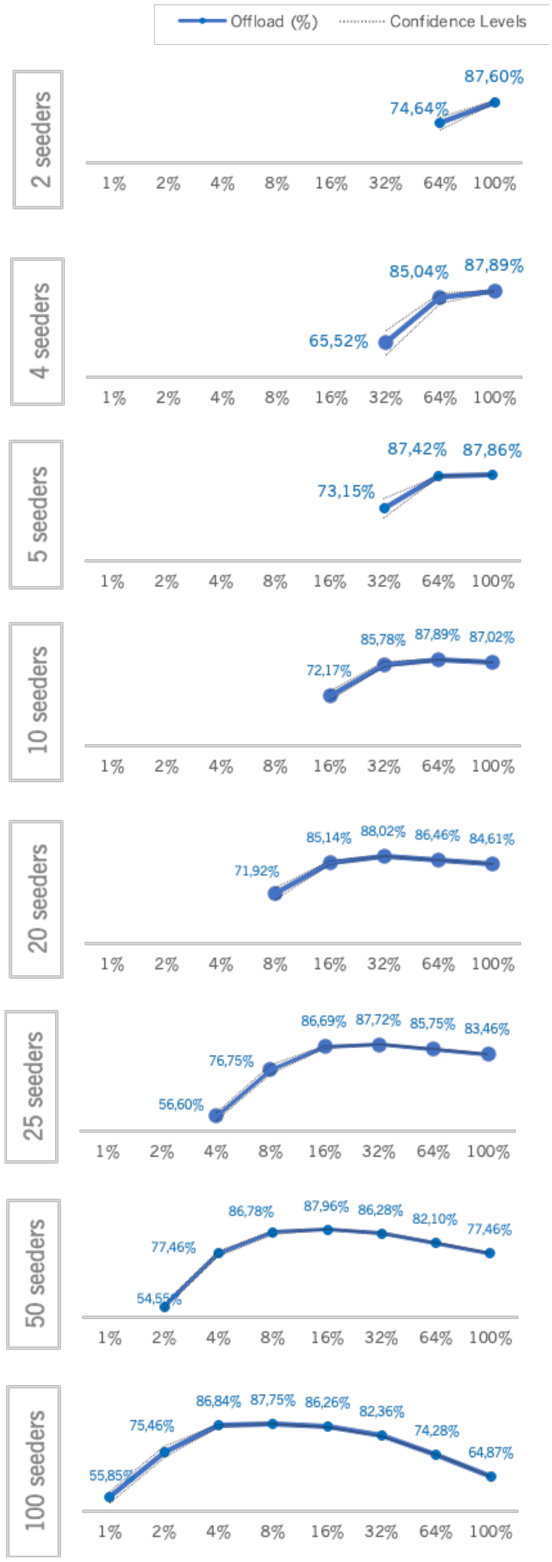


Figure 5.18: Offload Growth per nseed in E2 (100MB)

For 25 seeders,the minimum PFPS is 4%, so for that nseeder it was tested with 4%, 8%, 16%, 32%, 64% and 100% of the file per seeder. The result indicates that the ideal offload is 87.72%, at PFPS = 32%.

For 50 seeders, the minimum PFPS is 2%, so for that nseeder it was tested with 2%, 4%, 8%, 16%, 32%, 64% and 100% of the file per seeder. The result indicates that the ideal offload is 87.96%, at PFPS = 16%.

For 100 seeders,the minimum PFPS is 1%, so for that nseeder it was tested with 1%, 2%, 4%, 8%, 16%, 32%, 64% and 100% of the file per seeder. The result indicates that the ideal offload is 87.75%, at PFPS = 8%.

5.2.1.1 Percentage of file seeded file fleet-wide

To understand if the percentage of seeded file has a significant impact in the outcome offload, Figure **5.19** showcases the evolution of the V2V Offload per percentage of file seeded fleet-wide per nseeder, with a zoom-in view. The ideal offload is obtained when the percentage of file seeded fleet-wide is minor, as it can be visualised in the zoomed-in graph, growing until 1.5% seeded file and decreasing from that point until 28.10%.

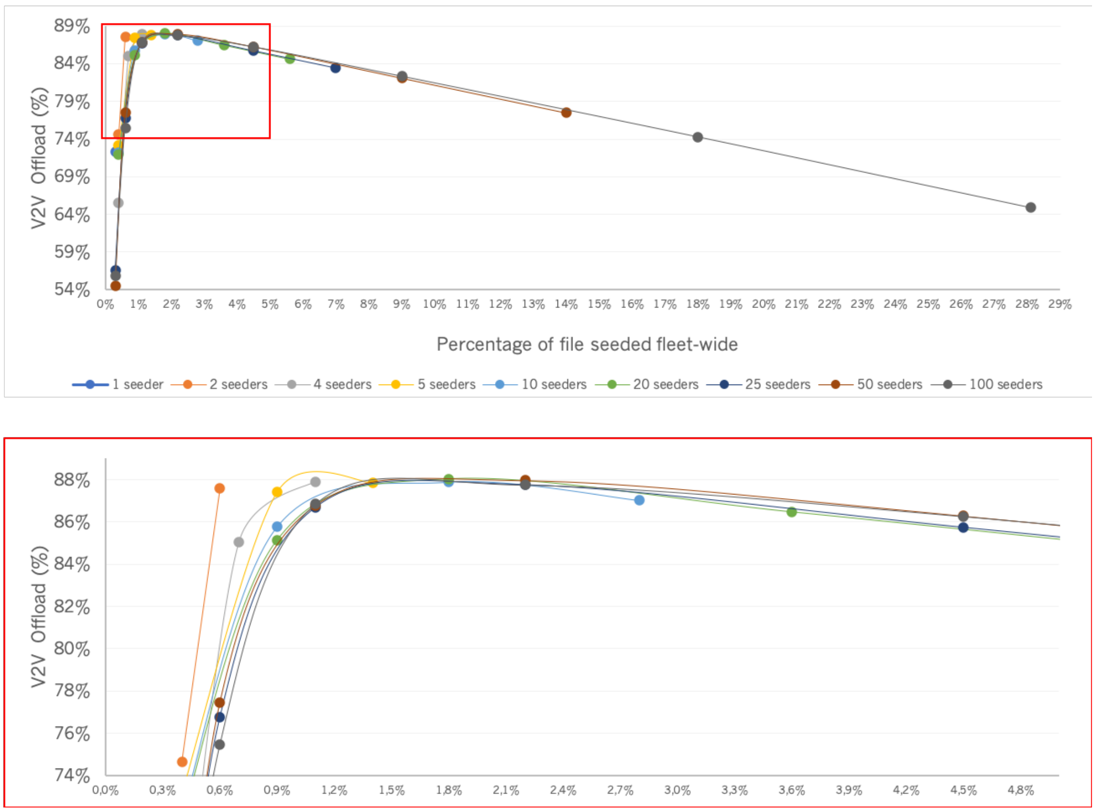


Figure 5.19: Percentage of file seeded fleet-wide (%) (100MB)

Though, as in the last Figure **5.19** the overall results per seeder were showcased, in Figure **5.20** it is presented the maximum V2V values per nseeder compared with the percentage of file seeded fleet-wide (the initial chunks seeded by cell).

Thus, the best percentage of file seeded fleet-wide is the one that represents the better outcome for the V2V offload. Hence, in this particular case, 1.50% of file seeded fleet-wide represents the maximum offload of the experiment (88.02%) at nseeder=20, which represents the highest savings represented in Figure **5.21**.

Hence, the more the percentage of file seeded fleet-wide does not correspond to a better offload. For instance, looking to the maximum value of the percentage of file seeded fleet wide (2.20% obtained at nseeder=25) the outcome is a lower V2V offload when compared with when nseeder=20. Also, all the values of percentage of file seeded fleet-wide higher than the ideal value (1.5%), do not correspond to better offloads (for example when nseeder=50 (seeded=1.80% and offload=87.96%) or when nseeder=100 (seeded=1.70% and offload=87.75%).

Therefore, there is no direct relation to the impact of the percentage seeded fleet-wide, but there is an ideal value that reflects the best outcome. Again, the value of nseeder=1 was not considered for the comparison because it is a lower offload when compared with the others (offload = 72.31% and the percentage of file seeded fleet-wide=0.3%).

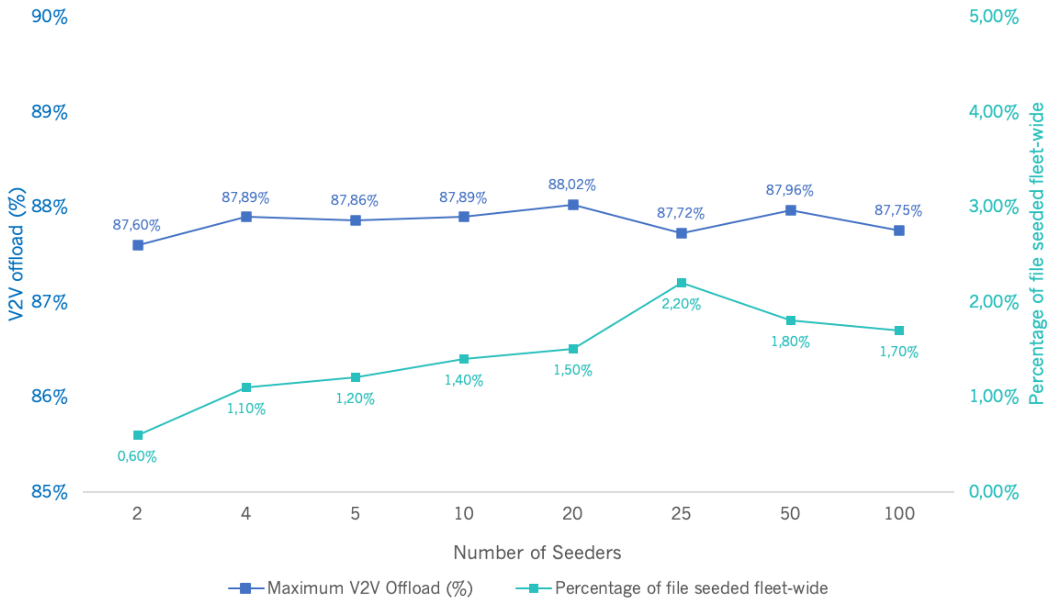


Figure 5.20: Percentage of file seeded fleet-wide compared with V2V Offload (%) (100MB)

5.2.1.2 Cost overview

For the E2 with the 100MB file, the maximum offload per number of seeder was considered. Therefore, it is assumed that the behavior is optimistic and it is reasonable to obtain the maximum offload. Also, again, if the OEMs do not use Veniam solution and cell-only solutions they have to expend 2492€ with the 100MB file size, since there is also one file circulating in the network.

So, taking into consideration Table **5.10** and Figure **5.18** the outcome is the maximum offload per nseeder, where the PFPS varies depending on the nseeder.

Thus, Figure **5.21** indicates the savings in € (in blue) per nseeder. Merged with the V2V Maximum Offload (in orange), it is clear that the offload is directly connected with the savings (€).

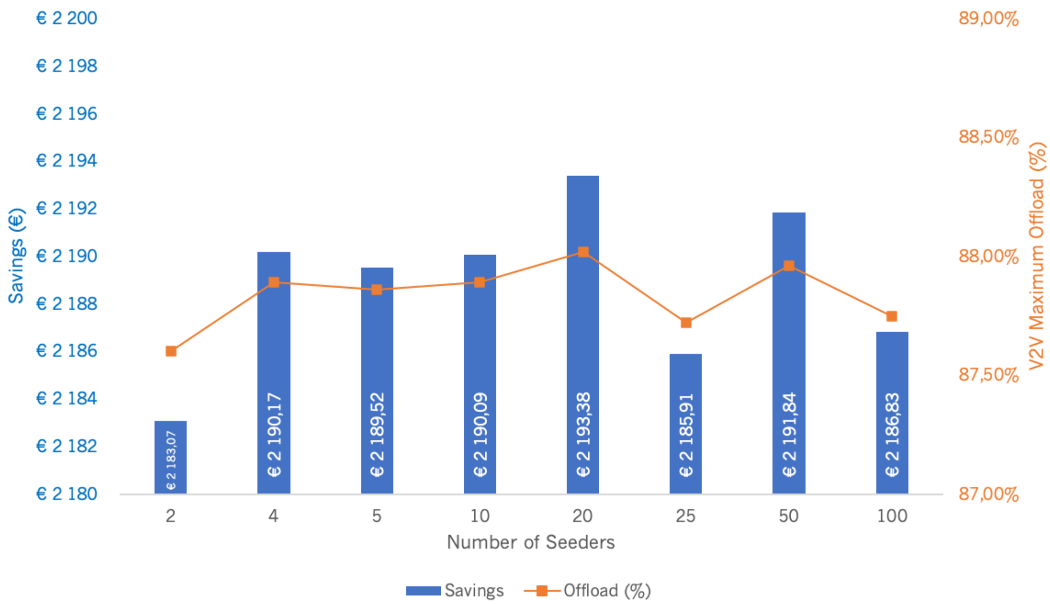


Figure 5.21: Savings of the maximum V2V offload (%) per nseeder (100MB)

The case of nseeder=1 was not considered since it does not have a high impact as from nseeder=2 on, and it was already mentioned in E1. Though, being the pessimistic scenario, nseeder=1 with a PFPS=100% results in a V2V offload=72.31%, representing a total saving of 1.801,87 €.

As the maximum offload percentages are similar from nseeder=2 on (between 87.5% and 88.5%), then the savings are also similar. In that sense, Figure **5.21** with a broader y-axis, allows the understanding of the difference between nseeder. It can be read that the maximum saving (the optimistic scenario) is at nseeder=20, with 2193,38 €, while the lowest is at nseeder=2 with 2183,07 €.

To conclude, having more nseeder does not translate into more savings necessarily, but it is directly connected with the capacity to offload more data.

5.2.1.3 Conclusion on 100MB file replication

- The highest offload is obtained when nseeder=20 and PFPS=32%.
- From the highest values of offload per nseeder (the green shadow in Table **5.10**) the lowest value is obtained when nseeder=1 and PFPS=100%.

- It is clear that having PFPS=100% does not always assure the maximum offload per nseeder. The clearest example of this is when nseeder=100 and the offload assumes a growth in the offload from 1% to 8% of the file and a decrease from 8% to 100% PFPS as seen in Figure **5.18**. Thus, there is an optimal value of PFPS that indicates the best offload per nseeder, and it is not always 100%.
- It is from nseeder=10 until nseeder=100 that having 100% of the file does not assure the highest offload.
- As the nseeder increase, the PFPS to obtain the highest offload is decreasing.
- As having 100% of PFPS does not assure the highest offload, the same behavior happens with the nseeder: The higher the nseeder does not correspond to the highest offload.
- There is an optimal value both for the nseeder and PFPS. In this E2, the ideal value was found, even though the exact optimal value was not and is proposed as future work.

5.2.2 1GB File

Similarly to the 100MB file, Table **5.11** displays the offload (in bold) and confidence level (in brackets) per seeder and per PFPS. In the green shadow, it is highlighted the best option per nseeder.

Table 5.11: Results of Experiment 2 - File replication amongst seeders (1GB)

Percentage of file per seeder

Number of Seeders	0.4%	0.8%	1%	1.6%	2%	3.2%	4%	6.4%	8%	12.8%	16%	25.6%	32%	51.2%	64%	100%
1																**12,67%** (4,02%)
2														**19,32%** (1,75%)	**19,43%** (1,78%)	**19,69%** (1,83%)
4												**22,35%** (1,03%)	**22,67%** (0,90%)	**22,99%** (0,85%)	**23,07%** (0,85%)	**23,19%** (0,79%)
5												**23,88%** (0,75%)	**24,13%** (0,71%)	**24,32%** (0,69%)	**24,41%** (0,69%)	**24,36%** (0,65%)
8										**24,71%** (0,72%)	**25,08%** (0,64%)	**25,54%** (0,55%)	**25,65%** (0,54%)	**25,77%** (0,54%)	**25,77%** (0,51%)	**25,57%** (0,47%)
10										**25,46%** (0,59%)	**25,72%** (0,57%)	**26,07%** (0,55%)	**26,16%** (0,52%)	**26,19%** (0,51%)	**26,18%** (0,50%)	**25,83%** (0,46%)
20								**26,73%** (0,35%)	**27,08%** (0,34%)	**27,45%** (0,35%)	**27,55%** (0,35%)	**27,65%** (0,34%)	**27,66%** (0,34%)	**27,54%** (0,34%)	**27,38%** (0,34%)	**26,33%** (0,39%)
25							**26,46%** (0,28%)	**27,41%** (0,27%)	**27,66%** (0,29%)	**27,95%** (0,27%)	**28,01%** (0,26%)	**28,07%** (0,28%)	**28,06%** (0,28%)	**27,91%** (0,30%)	**27,68%** (0,31%)	**26,33%** (0,38%)
40						**27,02%** (0,17%)	**28,03%** (0,16%)	**28,53%** (0,18%)	**28,68%** (0,18%)	**28,82%** (0,19%)	**28,85%** (0,20%)	**28,85%** (0,19%)	**28,81%** (0,20%)	**28,54%** (0,21%)	**28,20%** (0,23%)	**25,94%** (0,33%)
50					**27,19%** (0,10%)	**28,25%** (0,10%)	**28,53%** (0,11%)	**28,91%** (0,12%)	**29,02%** (0,12%)	**29,14%** (0,13%)	**29,16%** (0,13%)	**29,16%** (0,13%)	**29,08%** (0,12%)	**28,73%** (0,16%)	**28,30%** (0,20%)	**25,33%** (0,29%)
100			**27,76%** (0,07%)	**28,91%** (0,06%)	**29,23%** (0,05%)	**29,71%** (0,05%)	**29,86%** (0,05%)	**30,05%** (0,06%)	**30,10%** (0,06%)	**30,16%** (0,06%)	**30,15%** (0,07%)	**30,04%** (0,06%)	**29,92%** (0,06%)	**29,26%** (0,11%)	**28,34%** (0,18%)	**21,91%** (0,31%)
125		**27,87%** (0,07%)	**28,52%** (0,06%)	**29,40%** (0,05%)	**29,68%** (0,05%)	**30,09%** (0,04%)	**30,23%** (0,04%)	**30,41%** (0,04%)	**30,47%** (0,04%)	**30,52%** (0,05%)	**30,51%** (0,04%)	**30,37%** (0,05%)	**30,22%** (0,06%)	**29,44%** (0,13%)	**28,30%** (0,21%)	**20,10%** (0,34%)
200		**29,32%** (0,04%)	**29,72%** (0,03%)	**30,31%** (0,03%)	**30,51%** (0,02%)	**30,86%** (0,03%)	**30,98%** (0,03%)	**31,17%** (0,04%)	**31,24%** (0,04%)	**31,30%** (0,05%)	**31,27%** (0,05%)	**31,07%** (0,06%)	**30,86%** (0,07%)	**29,62%** (0,14%)	**27,76%** (0,21%)	**14,12%** (0,32%)
250	**28,20%** (0,04%)	**29,84%** (0,03%)	**30,17%** (0,02%)	**30,72%** (0,02%)	**30,90%** (0,02%)	**31,23%** (0,03%)	**31,37%** (0,03%)	**31,57%** (0,04%)	**31,64%** (0,04%)	**31,69%** (0,05%)	**31,66%** (0,05%)	**31,44%** (0,06%)	**31,20%** (0,07%)	**29,65%** (0,13%)	**27,29%** (0,22%)	**9,92%** (0,26%)

From Table **5.11** it is plausible to understand that at the pace the nseeders increase, the PFPS needed to obtain the highest offload is decreasing. Figure **5.22** illustrates the growth of offload per PFPS per nseeder. For 1 seeder, there is only the option of having 100% of the file, since it is the minimum percentage that a seeder can have. The offload of nseeder=1 is 12.67%, with a confidence level of 4.02%.

In the case of nseeder=2, the minimum PFPS is 50%. So, with was tested with 51.2%, 64%, and 100% percentages of file. The result indicates that the ideal offload is 19.69%, obtained at PFPS=100%.

In the case of nseeder=4, the minimum PFPS is 25%. So, with was tested with 25.6%, 32%, 51.2%, 64%, and 100% percentages of file. The result indicates that the ideal offload is 23.19%, obtained at PFPS=100%.

In the case of nseeder=5, the minimum PFPS is 20%. So, with was tested with 25.6%, 32%, 51.2%, 64%, and 100% percentages of file. The result indicates that the ideal offload is 24.41%, obtained at PFPS=64%.

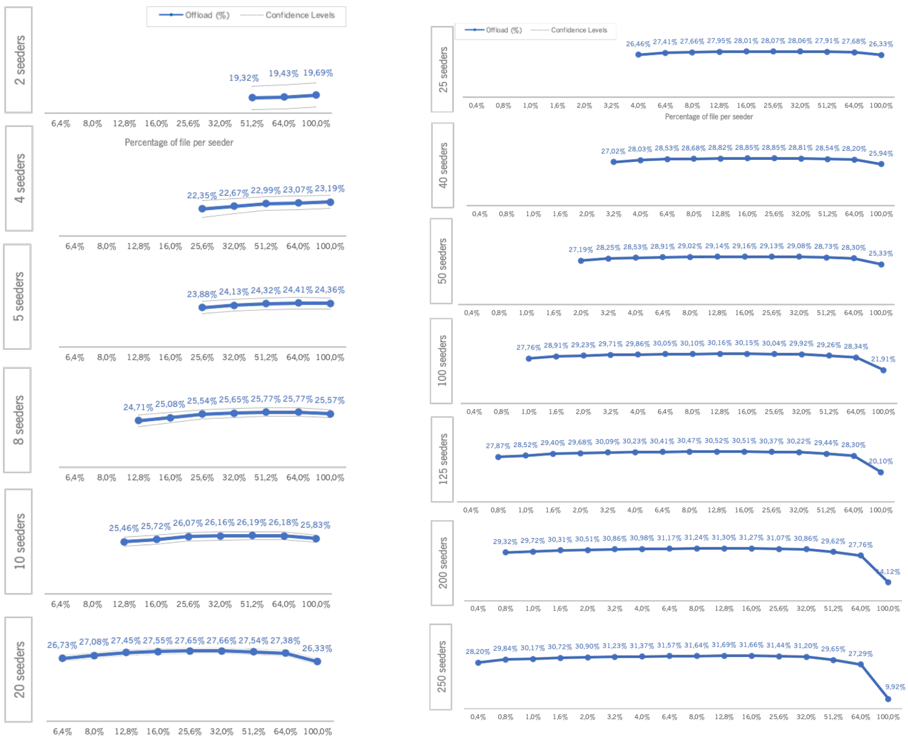


Figure 5.22: Offload Growth per nseeder in E2 (1GB)

In the case of nseeder=8, the minimum PFPS is 12.5%. So, with was tested with 12.8%, 16%, 25.6%, 32%, 51.2%, 64% and 100% percentages of file. The result indicates that the ideal offload is 25.77%, obtained at PFPS=51.2%.

In the case of nseeder=10, the minimum PFPS is 10%. So, with was tested with 12.8%, 16%, 25.6%, 32%, 51.2%, 64% and 100% percentages of file. The result indicates that the ideal offload is 26.19%, obtained at PFPS=51.2%.

In the case of nseeder=20, the minimum PFPS is 5%. So, with was tested with 6.4%, 8%, 12.8%, 16%, 25.6%, 32%, 51.2%, 64% and 100% percentages of file. The result indicates that the ideal offload is 27.66%, obtained at PFPS=32%.

In the case of nseeder=25, the minimum PFPS is 4%. So, with was tested with 4%, 6.4%, 8%, 12.8%, 16%, 25.6%, 32%, 51.2%, 64% and 100% percentages of file. The result indicates that the ideal offload is 28.07%, obtained at PFPS=25.6%.

In the case of nseeder=40, the minimum PFPS is 2.5%. So, with was tested with 3.2%, 4%, 6.4%, 8%, 12.8%, 16%, 25.6%, 32%, 51.2%, 64% and 100% percentages of file. The result indicates that the ideal offload is 28.85%, obtained at PFPS=16%.

In the case of nseeder=50, the minimum PFPS is 2%. So, with was tested with 2%, 3.2%, 4%, 6.4%, 8%, 12.8%, 16%, 25.6%, 32%, 51.2%, 64% and 100% percentages of file. The result indicates that the ideal offload is 29.16%, obtained at PFPS=16% and PFPS=25.6%.

In the case of nseeder=100, the minimum PFPS is 1%. So, with was tested with 1%, 1.6%, 2%, 3.2%, 4%, 6.4%, 8%, 12.8%, 16%, 25.6%, 32%, 51.2%, 64% and 100% percentages of file. The result indicates that the ideal offload is 30.16%, obtained at PFPS=12.8%.

In the case of nseeder=125, the minimum PFPS is 0.8%. So, with was tested with 0.8%, 1%, 1.6%, 2%, 3.2%, 4%, 6.4%, 8%, 12.8%, 16%, 25.6%, 32%, 51.2%, 64% and 100% percentages of file. The result indicates that the ideal offload is 30.52%, obtained at PFPS=12.8%.

In the case of nseeder=200, the minimum PFPS is 0.5%. So, with was tested with 0.8%, 1%, 1.6%, 2%, 3.2%, 4%, 6.4%, 8%, 12.8%, 16%, 25.6%, 32%, 51.2%, 64% and 100% percentages of file. The result indicates that the ideal offload is 31.30%, obtained at PFPS=12.8%.

In the case of nseeder=250, the minimum PFPS is 0.4%. So, with was tested with 0.4%, 0.8%, 1%, 1.6%, 2%, 3.2%, 4%, 6.4%, 8%, 12.8%, 16%, 25.6%, 32%, 51.2%, 64% and 100% percentages of file. The result indicates that the ideal offload is 31.69%, obtained at PFPS=12.8%.

5.2.2.1 Percentage of seeded file fleet-wide

Figure **5.23** introduces the evolution of V2V offload per percentage of file seeded fleet-wide per nseeder, with a zoom-in view to the highest values.

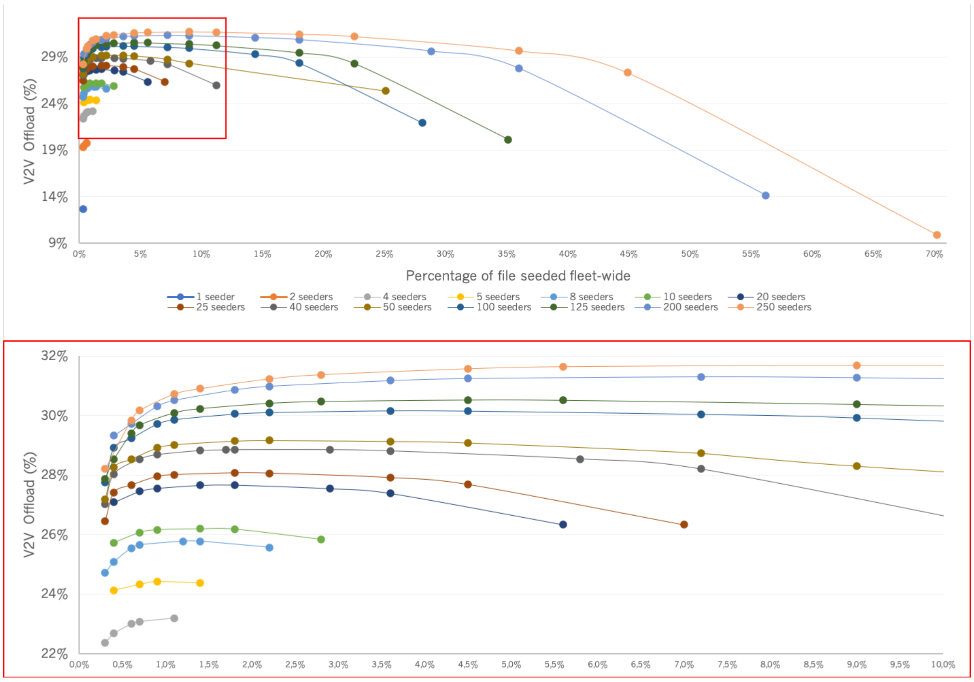


Figure 5.23: Percentage of file seeded fleet-wide (%) (1GB)

While in Figure **5.23** the overall results per nseeder were presented, in Figure **5.24** only the maximum V2V offload values per nseeder are showcased, compared with the percentage of file seeded fleet-wide.

Similarly to the 100MB file, the best percentage of file seeded fleet-wide is the one that results in the highest V2V offload. For the 1GB case, 9% of file seeded fleet-wide represents the maximum offload of the experiment (31.69%) at nseeder=250, which represents the highest saving value represented in Figure **5.25**. Again, the value of nseeder=1 was not considered for the comparison since it is a lower value when compared with the others (offload=12.67% and the percentage of file seeded fleet-wide=0.3%).

Overall, when combining the results of Figures **5.23** and **5.24**, it is possible to infer that the values grow until a certain point, and then start to decrease. For instance, if taking into consideration the maximum value (nseeder=250, offload=31.69%, percentage of file per seeder=9%, in Figure **5.23** represented with the longest line in orange) the value grows from the initial value to 9%, and then starts incrementally decreasing as the percentage of file seeded fleet-wide increases.

So, if looking to the maximum V2V values only per nseeder, the highest the percentage of file seeded fleet-wide, the better outcome. Thus, if looking at all values of one nseeder, there is always an optimal point where the maximum offload is obtained, which represents a specific percentage of file seeded fleet-wide. Hence, in that case (considering the scenario per nseeder), it is not plausible to conclude that the highest the percentage fleet-wide, the better the outcome.

Predominantly, the highest values of the offload are obtained at lower percentages of file per seeder.

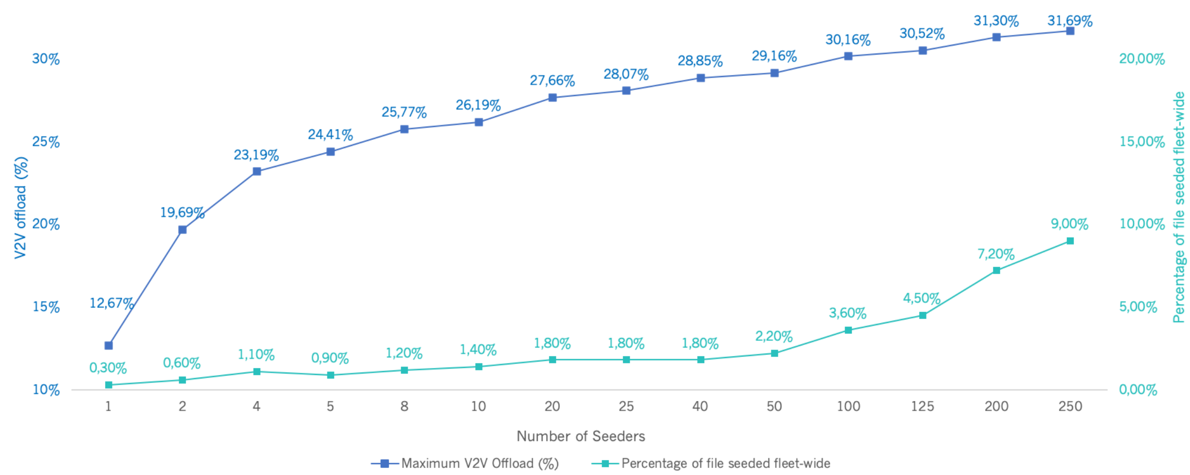


Figure 5.24: Percentage of file seeded fleet-wide compared with V2V Offload (%) (1GB)

5.2.2.2 Cost overview

For the E2 with 1GB file, and similarly to the 100MB, the maximum offload per number of seeder was considered to calculate the savings. Likewise, it is assumed that the behavior is optimistic and it is reasonable to obtain the maximum offload. If the OEMs wanted to offload the 1GB file using cell-based solutions, the company would expend 24 920€. Hence, taking into consideration the offloads represented in Table **5.11** and Figure **5.22** the outcome is the maximum offload per nseeder, where PFPS varies accordingly. Consequently, Figure **5.25** displays the savings per nseeder (in blue) and the V2V maximum offload (%) (in orange). Again, the growth in the savings accompanies the growth of the offload. Thus, for Experiment 2, for the 1GB file, the highest saving (optimistic scenario) is obtained when nseeder=250, with an offload=31.69% and a total saving of 7896.90€. The lowest saving (pessimistic scenario) is obtained when nseeder=1, with an offload=12.67% and a total saving of 3157.86€ out of the 24 920€.

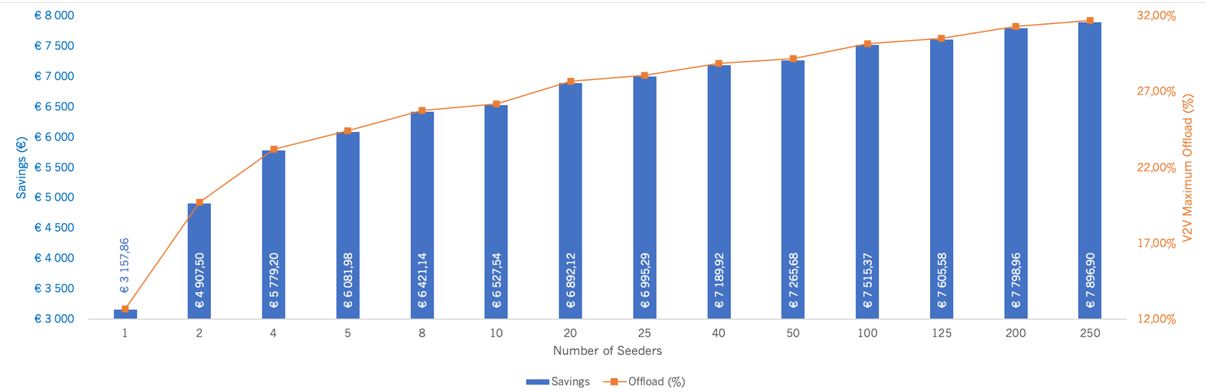


Figure 5.25: Savings of the maximum V2V offload (%) per nseeder (1GB)

5.2.2.3 Conclusion on 1GB file replication

- The highest offload is obtained when nseeder=250 and PFPS=12.8%.
- From the highest values of offload per nseeder (the green shadow in Table **5.11**) the lowest value is obtained when nseeder=1 and PFPS=100%.
- It is also clear that having PFPS=100% does not always assure the maximum offload per nseeder. Though, there is an optimal value of PFPS that indicates the best offload per nseeder, and it is not always 100%.
- It is from nseeder=5 until nseeder=250 that having 100% of the file does not assure the highest offload.
- As the nseeder increase, the PFPS to obtain the highest offload is decreasing.
- In contrast with the 100MB file size, in this 1GB case, the more the nseeder, the higher the offload obtained.
- The confidence level decreases as the nseeder increase

- There is an optimal value both for the nseeder and PFPS. In this E2, the ideal value was found, even though the exact optimal value was not and is proposed as future work.

5.2.3 Overall reflection on the file replication experiment (E2)

Similarly to Experiment 1, this subsection represents a compilation of the insights of the entire Experiment 2, which consisted in analysing the impact in the network of the replication of chunks of a file amongst seeder vehicles. The tests were also carried both with 100MB and 1GB file sizes, and Figure **5.26** embodies the final result.

Firstly, looking at both files' trendlines one can oversee they have different behaviors. While in the 100MB file (in yellow), the trendline assumes a maximum value, the 1GB file (in green), the trendline tends to increase as the nseeder increment.

So, for the 100MB the offload grows until a value that represents the highest offload and then it gradually decreases. For the 1GB, the more the nseeder, the higher the offload.

In the graph, it is also highlighted that there is a big gap between offload rates when comparing both sizes. For instance, when nseeder=100, for the 100MB the offload is 87.75%, whereas in the 1GB it is 30.16%. Thus, the financial impact (percentage-wise) is bigger when offloading files with minor sizes. Both these conclusions are generalist, but provide a clear overview of the impact of the file size in the offload rate when replicating the file amongst the seeders.

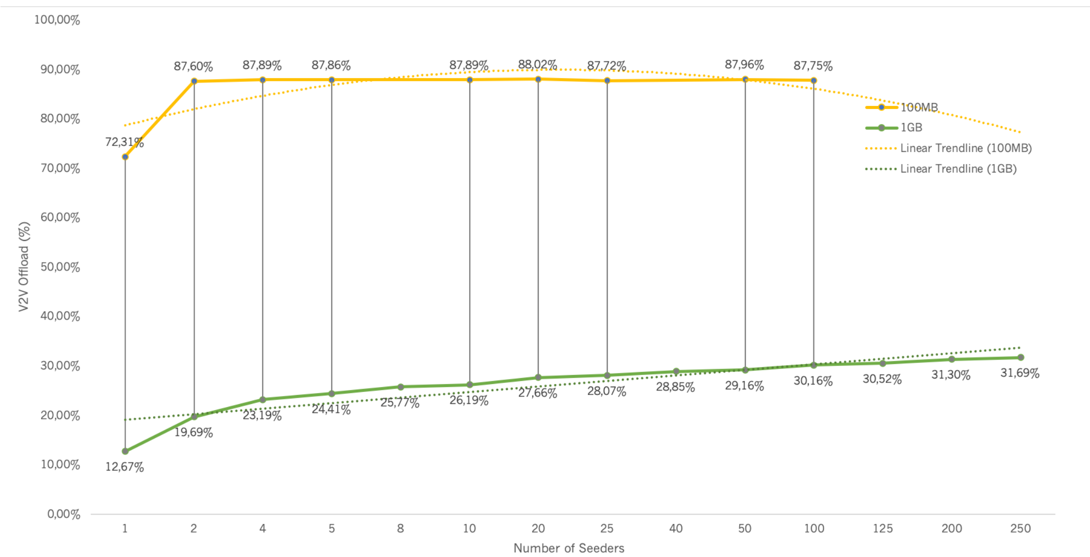


Figure 5.26: Comparison of the V2V Offload (%) of the file replication of the 100MB and 1GB files

The following Table **5.12** summarizes the outcomes of the replicating a file amongst seeders for both 100MB and 1GB file sizes.

Table 5.12: Highlights of Experiment 2 - File replication amongst seeder vehicles

Measure	**Description**
Cost Overview	The impact percentage-wise in the savings is higher in the 100MB file (around 88%, which corresponds to 2193.38 €) when compared with 1GB file size (around 32%, which corresponds to 7896.90€). Though, the utilisation of Veniam software translates in savings to the OEMs, even for a pessimistic scenario.
Offload Rate (%)	In the 100MB the offload rates are higher when compared to the 1GB, due to the time needed to connect to offload the file.
Number of Seeders	In the 100MB file, less nseeder are required to obtain the maximum offload (nseeder=20), while in the 1GB file, a higher number of seeders are required to obtain the maximum offload (nseeder=250).
PFPS (%)	In both file sizes, as the nseeder increases, the less the PFPS needed to obtain the maximum offload. In the 100MB to obtain the maximum offload (at nseeder=20), it needs a PFPS=32%, while in the 1GB to obtain the maximum offload (at nseeder=250), it needs PFPS = 12.8%.
Offload Growth(%)	In the 100MB file the offload overtakes a maximum and starts do decrease from that point on, whereas in the 1GB file the tendency is to increase the offload as the nseeder increase, considering the maximum V2V offload per nseeder

5.3 Comparison between file fragmentation (E1) and replication (E2)

As a way to summarize the results chapter, a comparison between the two experiments is presented, showcasing the major outcomes to conclude either if the product satisfies stakeholders' needs or not. The first experiment (E1) consisted of analysing both 100MB and 1GB file sizes when the file is fragmented amongst the seeders of the network. This exhibits that the sum of the percentages of file per seeder of all the seeders is equal to 100%, independently of the nseeder. The E1 determined that the seeding strategy chosen was the random, the chunk size used was 1MB and that each test should be run 10 and not 20 times.

The second experiment (E2) consisted of analysing both 100MB and 1GB file sizes when the file is replicated amongst the seeders of the network. This exhibits that the sum of the percentages of file per seeder of all the seeders is higher than 100%, independently of the nseeder.

Regarding the offload results, a comparison of the 100MB between E1 and E2 is showcased, followed by the same ideology applied to the 1GB file.

Figure **5.27** showcases the offload percentages of E1 and E2 for the 100MB file and the respective percentual growth from E1 to E2. It is straightforward that file replication brings an advantage compared to fragmentation. Also, the replication of the file for minor file sizes (100MB) performs better when in comparison with higher file sizes (1GB).

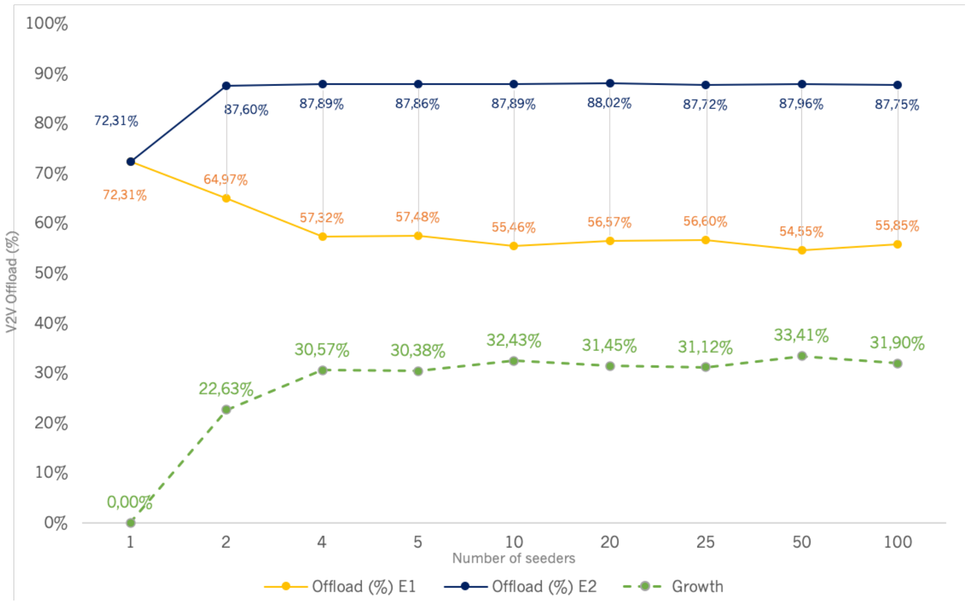


Figure 5.27: Comparison between V2V offload (%) of E1 and E2 for 100MB file

Being Experiment 2 more beneficial efficiency-wise, then the savings will have a major impact in E2 rather than E1. Figure **5.28** showcases the savings of E1 and E2, together with costly growth. The maximum saving is obtained at nseeder=20, while the biggest growth is at nseeder=50 (both of the values are highlighted in red in the graph).

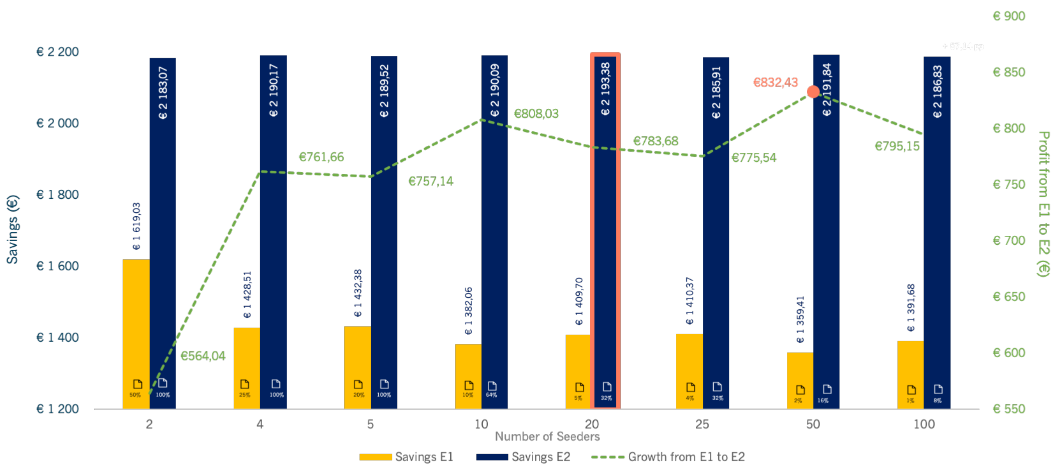


Figure 5.28: Comparison between savings of E1 and E2 for 100MB file

Also, a comparison for 1GB file between E1 and E2 is performed, shown in Figure **5.29**, together with the respective percentual growth from E1 to E2. It is clear that for the 1GB the growth is not as high as with the 100GB, though E2 still brings benefit over E1.

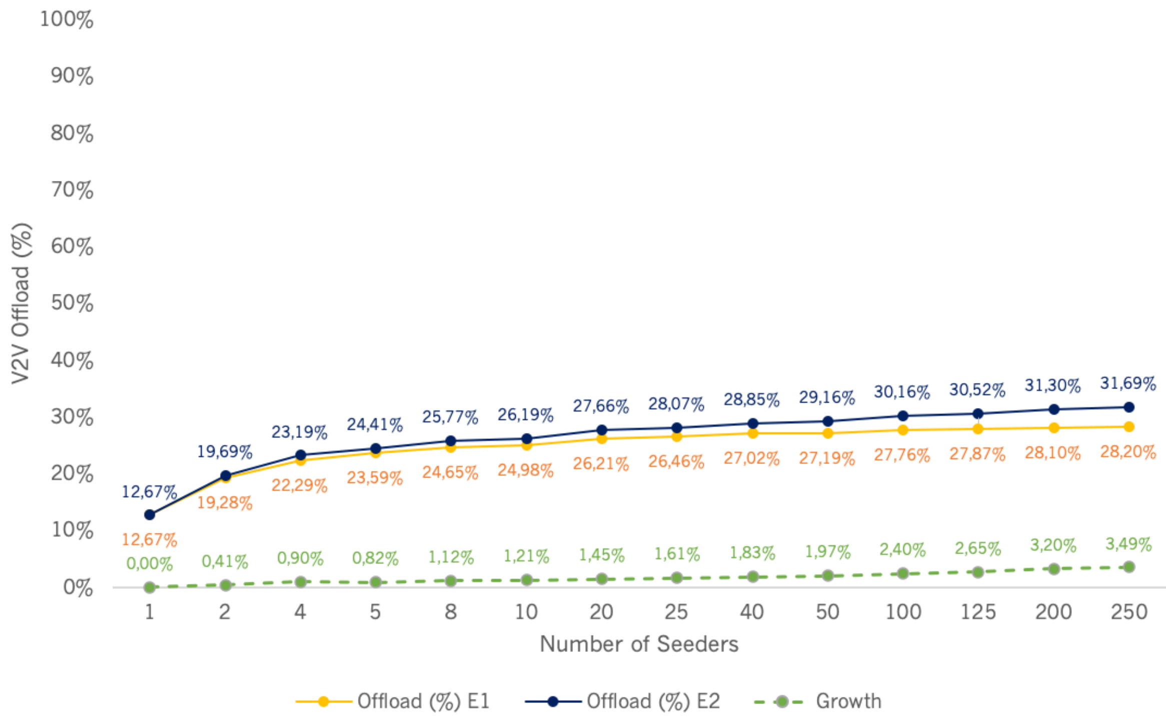


Figure 5.29: Comparison between offload of E1 and E2 for 1GB file

Therefore, as E2 is more beneficial than E1 the savings will also upsurge. Figure **5.30** showcases the savings of E1, E2 and a costly growth. The maximum saving and biggest growth are obtained at nseeder=250 (both of the values highlighted in red in the graph).

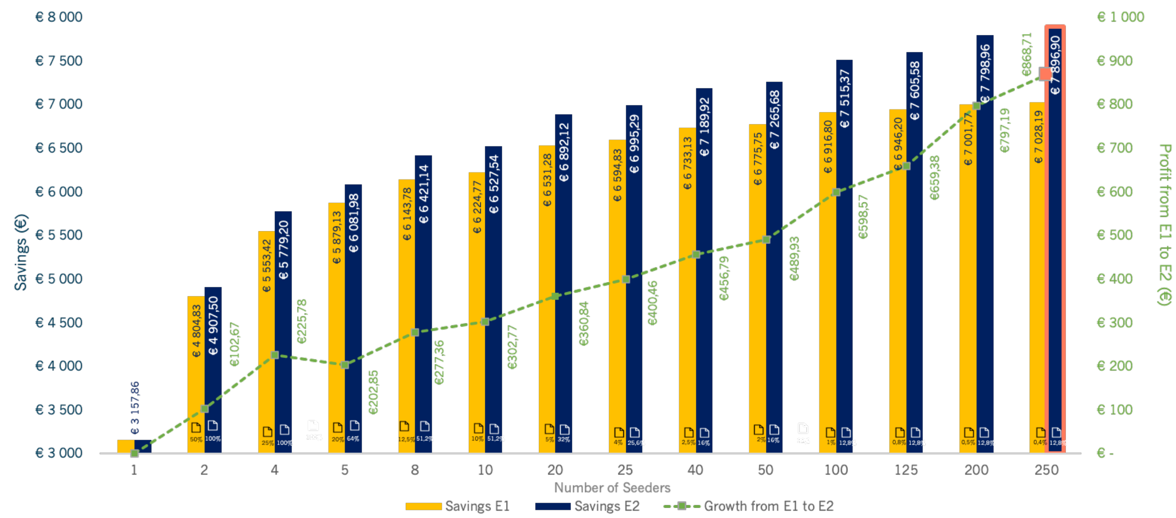


Figure 5.30: Comparison between savings of E1 and E2 for 1GB file

Overall, percentage-wise it is explicit that the 100MB results obtain higher offloads when compared with 1GB, both for E1 and for E2. Also, E2 proves to be a better strategy than E1. Therefore, replicating chunks amongst seeders of a network is considerably a better option than fragmenting them, both for minor and higher file sizes, but with a bigger impact on minor ones.

5.4 V2V data cost dashboard

Albeit the creation of a dashboard was not a goal from this master thesis project, after reuniting all the results and diverse data analysis, the concept of facilitating the visualisation of big amount of data emerged. Hence, a dashboard was developed in PowerBi.

Currently, the Veniam V2V product is projected to be inserted as an add-on to the main Veniam service, the Wi-Fi Offload.

Veniam does not possess a data visualisation tool in what concerns V2V, which would facilitate instantly the comprehension of the savings using the technology. Hence, the dashboard was conceived with the end goal of being utilised by OEMs.

As explained, the dashboard was not a requirement for this project. Nevertheless, it will be suggested to Veniam, but not implemented (at least, not at the time this dissertation was written, leaving to open option to the company to invest in this framework - even include it in NOC- or not).

The following figures illustrate the visual of the framework represented in Figure **5.31**.

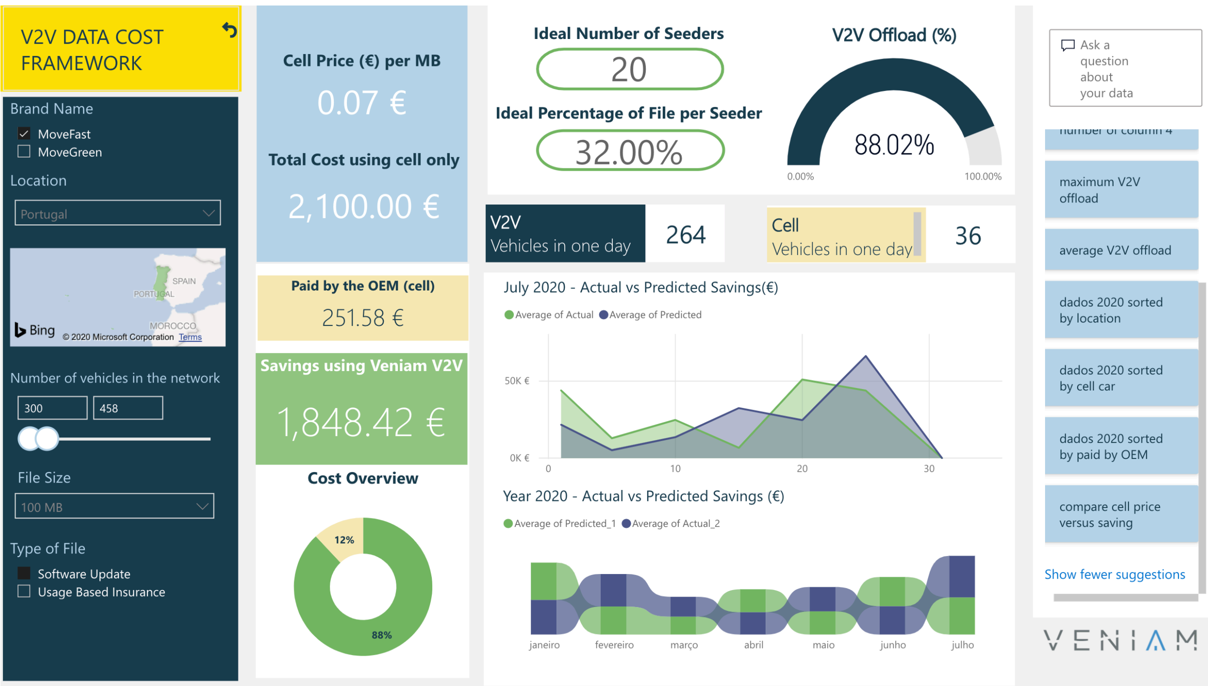


Figure 5.31: V2V data cost dashboard

The framework is adaptable to each specific OEMs, but has a core functional basis:

1. Select the brand or entire fleet of the OEMs;
2. Select the Location of where the file is being shared;
3. Select how many vehicles are in the mesh network;
4. Choose the size of the file to share in the network;
5. Indicate the type of file to share (software update, map update,...)
6. The dashboard provides the ideal number of seeders and best PFPS to obtain the maximum V2V Offload (%), that translates into V2V vehicles/ cell vehicles;
7. The financial results per file shared;
8. The results of the predicted and actual savings to the OEMs, monthly and yearly.

5.4.1 Filters

The section in the left in dark blue includes the filters that generate the results for the dashboard. Firstly, the OEMs chooses the brand names within the entire OEMs that it needs to offload. It can choose all of the options. The names "MoveFast" and "MoveGreen" were used as generic brands of a specific OEMs fleet.

Secondly, the OEMs chooses the location where the file is being offloaded. For this example there were used Portugal, Japan, and Germany countries. Depending on the option chosen, the map zooms in to the specific country.

Thirdly, the OEMs chooses the interval of the number of vehicles existent in the mesh network. Here, values from 300 to 2000 were considered.

Then, the file size is chosen, from 0.5MB to 3GB.

Lastly, the type of file is selected from "Firmware Update" to "Usage Based Insurance". The right upper button of an arrow resets all the filters to the initial starting point.

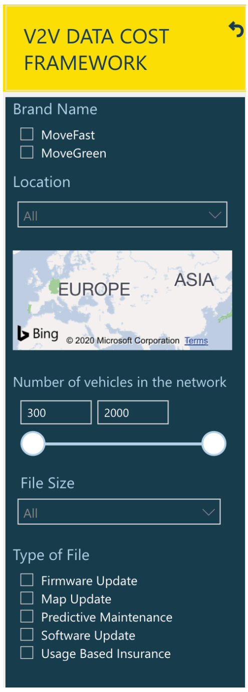


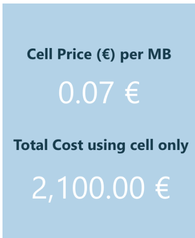
Figure 5.32: Filters

5.4.2 Costs overview

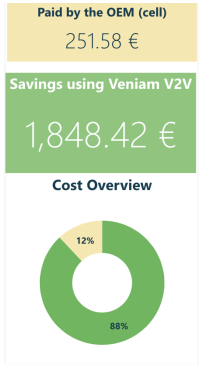
The cell cost is dependent on the geographic location.

Thus, by selecting the location in the filters, the price of cell cost per MB is displayed on the dashboard. Then, it is calculated the value that the OEMs would spend if it was only using cell-based solutions to disseminate the file in the network, as shown in Figure **5.33a**.

In yellow it is showcased the price (€) paid by the OEMs due to the offload done in the seeding and aposteriori processes, as shown in Figure **5.33b**. In green, it is embodied the outcome of using Veniam's V2V Wi-Fi software, representing the savings. Below there is a pie chart representing the proportions relations of expenses and savings.



(a) Cell Cost



(b) Expenses and Savings

Figure 5.33: Costs overview

5.4.3 Ideal parameters outcome

This subsection is the ideal outcome from the filters used that will be used by the OEMs to disseminate data in the network. The ideal scenario is having a back database with optimization calculations of the optimal number of seeders and an ideal percentage of file. Nevertheless, for this illustration it was used the work done previously, finding the ideal and not optimal values.

As shown in Figure **5.34**, it showcases the "ideal number of seeders" given the number of vehicles in the network, the "ideal PFPS", the "V2V Offload (%)", and lastly the estimate of vehicles that have acquired the data from V2V or from cell.

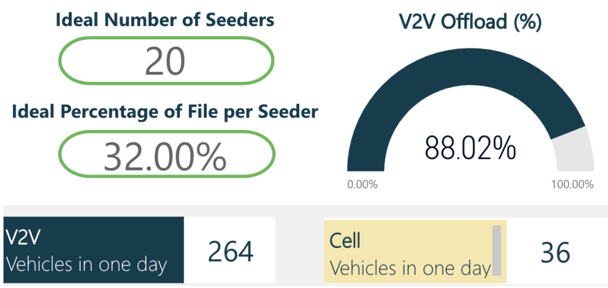


Figure 5.34: Insights of the ideal outcome to be implemented in the network

5.4.4 Monthly and yearly savings

This section illustrates the savings of the OEMs over the month (in the first graph of Figure **5.35**) and over the year (in the second graph). In both, it is showcased the difference between the actual and predicted savings (€).

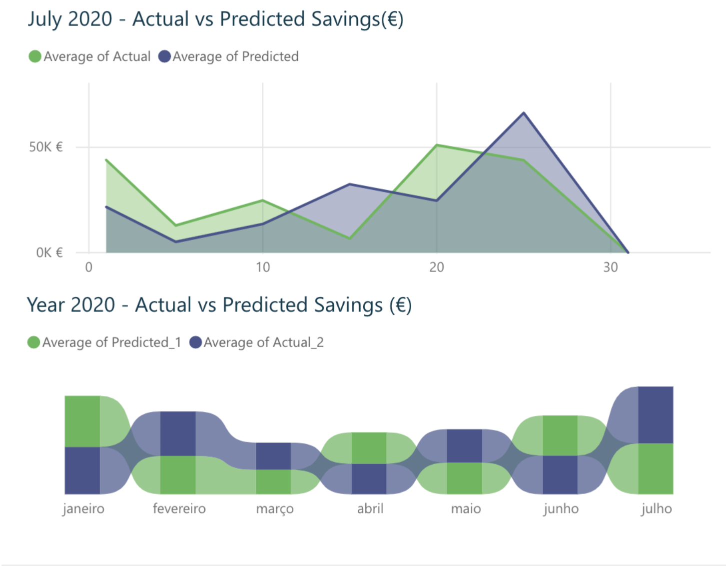


Figure 5.35: Monthly and yearly view of predicted and actual savings

5.4.5 Data questions

The right part of the dashboard includes a section where the user can ask directly a question to the framework. For instance "Maximum V2V Offload" or "Dados2020 sorted by location" and it presents the database ordered by geography.

Chapter 6

Conclusion

Veniam is building the data networking platform for future mobility, being able to maximize the utility of vehicles by creating mesh networks of connected vehicles. With ongoing projects with auto OEMs and the automotive industry, Veniam is looking to expand its footprint in the future mobility ecosystem. The Product Management team at Veniam is responsible for designing a competitive product that fits the needs of the current customers and that challenges existing paradigms to expand the company's footprint into new markets. As such, the startup commits to have a deep understanding of the competitive landscape, solid financial models to measure a customer's lifetime value to calculate how Veniam can maintain its target revenue in deployments across geographies.

Thus, this closing chapter reviews critically the work developed during the elaboration of this thesis, including suggestions for possible future developments in the field and in the research developed.

6.1 Implementation

As said previously, Veniam had a lack of knowledge in defining the parameters to the best V2V solution. The outcome of this master thesis helps Veniam define in a better way their V2V offering, by providing a clear view of the cost and efficiency impact of their technological product.

Thus, the results can be used in three different contexts:

- **To the engineering team:** The variables studied in data analysis for this project are the ones explored by the engineering team (team that did not focus in the product perspective, including its attractiveness and product conceptualization from the competitiveness overview to the financial analysis). Thus, after the analysis performed both in the product and in the data of the testbed, the data outcomes are a source of value for the input of the engineering team, which are a factor of variance in the outcome of an ideal offload.
- **To the sales team:** The results can be used in Veniam's master deck to showcase the benefits of V2V, together with the dashboard developed in PowerBi that provides a visual insight of the benefits of the technology, when introducing Veniam to the different stakeholders.
- **To the product team:** The product was intensively and deeply analysed, proving its ultimate competitiveness, explained in the points below.

Henceforth, the ultimate goal of the project of this master thesis is now accomplished, being categorised in the following outcomes:

- The results from the testbed measurements were used to define arguments based on data that supports Veniam value proposition of moving large amounts of data between vehicles and the cloud.
- Clear understanding of how upcoming data requirements can be fulfilled in a cost-effective way using Veniam Platform, more specifically V2V Technology
- The V2V product portfolio is deeply analysed and the financial competitiveness of the company was tested, identifying market and business opportunities that enhance Veniam's position in the future mobility market ecosystem
- Tackle the specific point to make this product a scalable solution that addresses key market needs

Veniam's product portfolio will incorporate the main results derived from the master thesis work at the startup.

6.2 Critical analysis on key findings

As a final overview of all the work, a strategic overview of the product is compiled in a VRIO analysis in Figure **6.1**, which consists in understanding if the technology is Valuable, Rare, Inimitable and if the company is Organized.

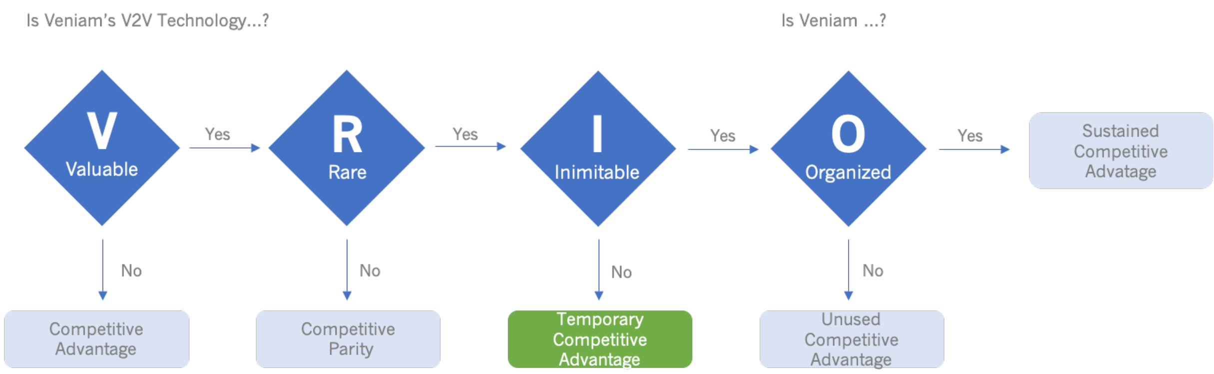


Figure 6.1: VRIO analysis

Valuable The proof of value was obtained both in a financial and optimization point of view. It proves it has the essential requisites to be considered a vanguard product, due to the future connectivity necessities of the vehicles. So, Veniam's V2V product is valuable.

Rare There are other solutions in the market that bring closer the goal of sharing data amongst vehicles. But none brings together the optimization of using cities Wi-Fi hotspots to tackle the connectivity needs of CASE vehicles, in a cost-effective way, with an impact on delay-tolerant applications. Most current market solutions use mainly cell technology with the focus of the safety applications, being an expensive solution. So, Veniam's product is rare.

Inimitable Veniam possesses the closest product when it concerns delay-tolerant non-safety Wi-Fi V2V data sharing. Though, the technology is not fully protected and the existent patents do not cover the whole V2V usage. Thus, Veniam should be aware of the closest competition that possesses similar products, but using other sources of vehicular technology such as DSRC or cell, since it can contribute to a future negative impact at the company. So, for now, Veniam V2V product is stable and ingenious. Yet, it is not inimitable.

Organized If the product obtains the "Inimitable" requisite, then it is close to reach a sustained competitive advantage, due to the irreproachable resources the startup has.

6.3 Risks and contingency plan

Risks Risk acknowledges the unpredictability of the ideal activity, usually with unwanted repercussions.

1. COVID-19: The pandemic situation brought undesirable outcomes regarding investments in innovation and technology, as well as employment status. Thus, it is a risk for Veniam the lack of interest shown by its stakeholders that supported and believed in the product up until now.
2. 5G: The major competitor of the Veniam Wi-Fi technology is the cell novelty of 5G. Even though there is not sufficient infrastructure and ideal conditions to use the technology in vehicular communications, it is a risk to Veniam if 5G is increasingly being adopted.
3. Merged or Acquired by a Technological Company: The investors are now focused either on investing in startups of higher series or acquire them. Also, there are differences in the companies cultures as well as different types of communication and levels of transparency. Though, it is a risk if a technological company acquires Veniam and mislays the core message of Veniam and its valuable stakeholders.
4. Competition Overpower: It is a risk if another company mimics Veniam's value proposition with the same technology

Contingency Risk contingency is a procedure to conduct a risk if it occurs, which does not reduce the risk itself, but reduces the impact in case it occurs.

1. Invest in market research: The current stakeholders are OEMs and Tier-1s. Though, as they currently have their own priorities that disregard the research and technological investments, they are focusing on production and recovery from the loss of the pandemic. Ergo, Veniam should shift the initial focus and explore other mesh network niches that might have emerged recently, since not all mesh networks involve vehicles, but can include bicycles, tractors, buses, trains, trucks and so on. For example, Veniam could focus in services fleets such as UBER, where V2V would be applied in using the tech with machine learning algorithms to understand if the passengers are close to each other and if they want to reach the same destination and therefore save on the cost of the shareable transportation.
2. Adapt to the new infrastructures: In case that 5G gains effectively a higher significance with a cost efficiency focus, with well-prepared road infrastructure and vehicles equipped directly to that communication technology, then Veniam software might slowly become worthless and easily substituted. Then, Veniam should maintain the core of its value proposition, but changing aspects that allow the capability to continue scaling up.
3. Be a step ahead: A conscious and prudent planning with compliance management, together with the assurance of the right patents will lead to a better transition, without loss of the core message of Veniam, maintaining the essence of the product
4. Assure the right patents at the right time to prevent conflict of interest. If not, there is the need to refocus the investment made through these past 8 years.

6.4 Future work

Several aspects of this master thesis are requiring a deeper investigation. Most of them are related to the data analysis of the testbed. As it has been constantly repeated throughout the thesis, the work developed is not an optimization process of the optimal scenario. Though, it is an analysis of an ideal scenario.

Firstly, the nseeders tested were not a continuum of whole values, that would retrieve better insights in offload terms. Thus, it would be interesting to see the difference between the results from this work and the work considering all the whole values in an interval.

Secondly, the testbed used to draw conclusions consists of a one day only behavior of the network, in a highly-dense environment. Hence, the research of additional days would bring additional significance to the current results and appealing to replicate to different cities in the same context (same density of vehicles). So, knowing the behavior of additional days, the savings per week, month, or year would be closer to the realistic scenario. Also, it would be possible to recognize if the results are dependent on the quality of the vehicles or in the number of vehicles in a network.

Thirdly, the initial tests were carried with chunks of 1MB, 5MB, and 10MB. Even though the 1MB chunk was chosen, there is further need for investigation in the chunk size. Aspects as understanding if the optimal chunk size depends on the file or if sizes less than 1MB are feasible, would contribute to enhancing the ideal V2V performance. Again, testing not only with whole numbers, but with different values within an interval to understand if it delivers better offload results. Also, further literature review on NC would provide the first steps for the optimization of the flow of the data, regarding the best way of chunking a file. Briefly, NC consists of breaking the file into packets that do not necessarily travel the same route, but eventually arrive at the same destination. Thus, the end destination gathers the packets and forms the original message. The cons of this method are that when the traffic of the network is high, bottlenecks appear, resulting in long delays, overpowering some routes and under-utilising others. As the variable of time was not integrated into the study, the research of the network at the time would not add value to the outcome of the project.

Fourthly, in the thesis is assumed that for the same percentage of seeded data, the cost is the same no matter how many nseeders there are. Though, in realistic environments, the behavior is not as linear as expected. Therefore, the research on the impact of having more number of seeders with less percentage of a file is crucial for understanding if it changed radically the behavior it has been assumed in this thesis. Also, to understand if the cell networks are available anywhere and would have the capability to connect fast to more nseeders, at the same cost.

Fifthly, it is recommended the inclusion of the time constraints in the study presented in this project, since it was not a relevant parameter to this master thesis. Overall, on the 100MB file, it is clear that fewer nseeders provide a better result than having more nseeders. So, understanding what is the twist in this result is significantly important, mostly because it is likely related to the time constraints, causing bottlenecks.

Sixthly, as mentioned in chapter **2.4** by Mezghani et al. (2016), SIEVE algorithm considers the user interest on the dissemination of the data, leveraging the available networks at the time. Even though it was not much explored for this dissertation, it is the highly interest of Veniam to consider a methodology like this, since Veniam aims to satisfy its stakeholders needs as they request (both direct - OEMs and indirect - driver and passengers).

Lastly, as mentioned in subsection **2.2.1.2**, epidemiological mathematical models research on the impact of the vehicular opportunistic network might bring additional interesting outcomes, especially on the optimization model and parallelism on an epidemic spread.

To conclude, even though all of the goals and research questions stated in the introduction chapter were achieved, there is still room left for improvements. Regarding the restraints and hurdles the project was limited by COVID-19 that impacted the project in the validation of the results with real stakeholders, since the communication processes were delayed and projects put on hold. Nevertheless, as the startup moved easily to a remote environment, the continuation and development of the project were carried seamlessly.

Overall, Veniam's V2V technology is perceived to OEMs as surprising and exceeds expectations in what regards the adaptability of the platform in highly dense, suburban, or rural areas, either on the move or static. Therefore, the thesis concludes that for V2V Non-Safety Delay-Tolerant applications, this Wi-Fi product highly satisfies the stakeholders' needs, both efficiency and costly wise, being advised to Veniam constant research around this ingenious topic to maintain a sustained competitive advantage.

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Appendix A

Demonstration for stakeholders

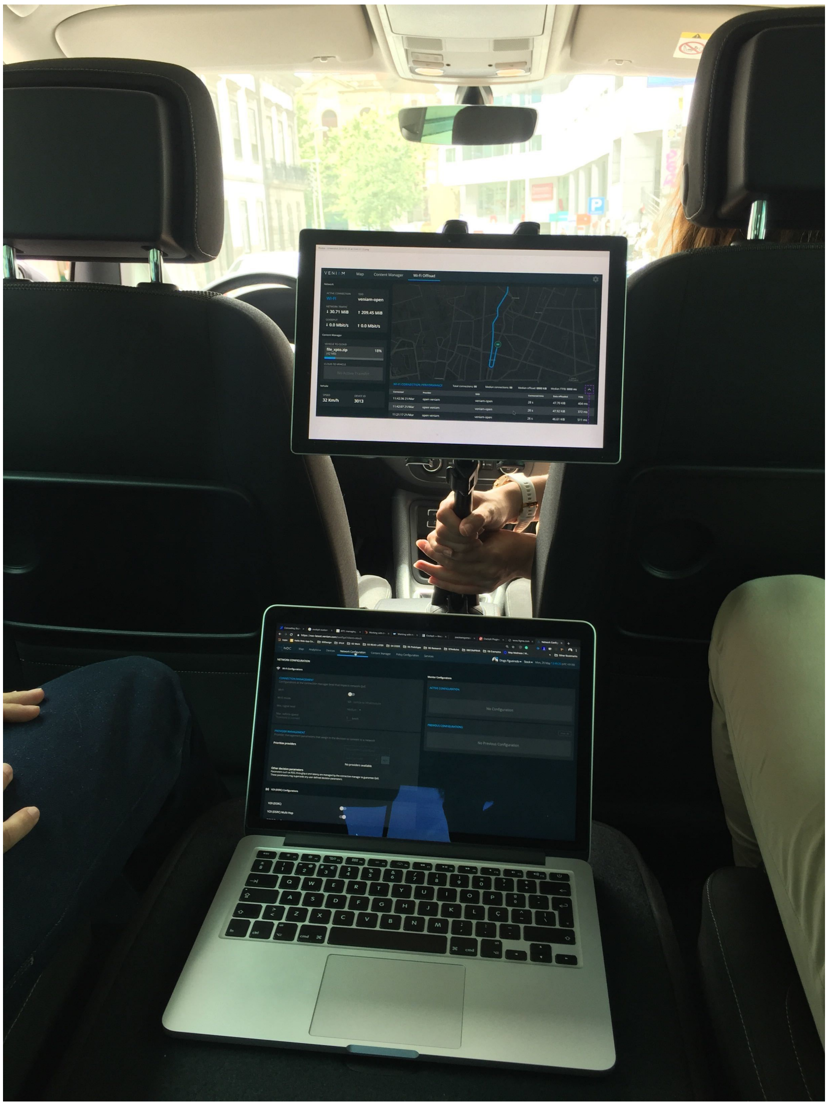

Figure A.1: Demonstration of Veniam's software made to stakeholders

Appendix B

Worldwide Cellular Cost

The table is ranked from the cheapest average price of 1GB to the most expensive worldwide.

Table B.1: Worldwide Cellular Cost (Cable.co.uk, 2020b)

Rank	**Name**	# Packages	Avg Cost 1GB (€)	Highest Cost 1GB (€)
1	India	57	0,26	1,40
2	Kyrgyzstan	12	0,27	0,48
3	Kazakhstan	26	0,49	0,79
4	Ukraine	12	0,51	1,38
5	Rwanda	36	0,56	2,78
6	Sudan	35	0,68	1,63
7	Sri Lanka	38	0,78	2,09
8	Mongolia	26	0,82	2,26
9	Myanmar	11	0,87	1,48
10	Congo	31	0,88	5,05
11	Israel	25	0,90	6,89
12	Russian Federation	31	0,91	2,19
13	Bangladesh	53	0,99	3,81
14	Finland	20	1,16	2,17
15	Malaysia	60	1,18	3,27
16	Monaco	3	1,21	1,70
17	Indonesia	60	1,21	4,25
18	Bhutan	37	1,25	2,72
19	Iran	36	1,28	4,75
20	Vietnam	41	1,31	6,45
21	Poland	57	1,32	5,21
22	Denmark	24	1,36	4,52
23	Cambodia	36	1,49	6,25
24	Egypt	37	1,49	4,55
25	Ghana	54	1,56	4,75
26	Afghanistan	46	1,60	3,96
27	Armenia	29	1,65	3,07
28	Morocco	34	1,66	5,25

Rank	**Name**	# Packages	Avg Cost 1GB (€)	Highest Cost 1GB (€)
29	Western Sahara	34	1,66	5,25
30	Cameroon	36	1,71	6,89
31	Italy	44	1,73	11,31
32	Jordan	49	1,79	5,99
33	Pakistan	58	1,85	7,15
34	Chile	60	1,87	6,05
35	Dominican Republic	9	1,88	3,12
36	Austria	59	1,88	11,08
37	Romania	19	1,89	4,90
38	Guinea	27	1,94	2,64
39	Burundi	31	2,00	3,70
40	Kuwait	36	2,01	11,52
41	Lithuania	11	2,06	4,81
42	Palestine	30	2,06	9,19
43	Slovenia	28	2,21	10,17
44	Nigeria	57	2,22	13,79
45	Nepal	27	2,25	6,43
46	Zambia	45	2,25	8,44
47	Turkey	56	2,25	15,82
48	Belarus	25	2,36	7,97
49	Lesotho	30	2,43	7,56
50	Australia	56	2,47	7,59
51	Peru	23	2,48	3,35
52	Réunion	12	2,51	15,82
53	Azerbaijan	35	2,69	9,38
54	Kenya	54	2,73	9,97
55	Thailand	59	2,78	9,58
56	Uruguay	41	2,80	10,73
57	Moldova	15	2,82	8,76
58	Bahrain	20	2,83	7,96
59	Tunisia	37	2,87	13,42
60	Ethiopia	8	2,91	3,86
61	Niger	45	2,92	14,36
62	France	49	2,99	19,21
63	Guernsey	23	3,05	25,85
64	Argentina	36	3,05	10,59
65	Åland Islands	6	3,10	8,42
66	Mauritania	14	3,12	7,83
67	Philippines	19	3,16	7,64
68	Albania	33	3,22	13,18
69	Uzbekistan	56	3,27	11,89
70	Senegal	21	3,28	13,79
71	Georgia	36	3,33	18,98
72	Madagascar	26	3,39	8,39

Rank	Name	# Packages	Avg Cost 1GB (€)	Highest Cost 1GB (€)
73	Lao People's	37	3,42	4,65
74	Brazil	27	3,50	10,18
75	Fiji	14	3,57	18,40
76	B. and Herzegovina	20	3,58	7,78
77	Malawi	18	3,59	7,51
78	Macedonia	37	3,62	18,24
79	Sweden	58	3,66	15,91
80	Estonia	31	3,67	18,09
81	Singapore	37	3,67	9,34
82	Mauritius	11	3,71	6,98
83	Liberia	35	3,75	12,50
84	Iceland	23	3,78	14,19
85	Spain	56	3,79	10,55
86	Jersey	30	3,82	25,85
87	Ireland	24	3,95	22,61
88	Hong Kong	51	4,00	16,31
89	Côte d'Ivoire	11	4,10	6,89
90	Syria	29	4,14	15,76
91	Cape Verde	13	4,25	10,22
92	Montenegro	13	4,26	6,16
93	Luxembourg	17	4,39	11,31
94	Timor-Leste	25	4,48	9,09
95	Guatemala	19	4,53	7,24
96	El Salvador	27	4,55	10,50
97	Belize	34	4,57	7,43
98	Qatar	21	4,62	13,73
99	Jamaica	23	4,64	7,43
100	Burkina Faso	34	4,69	11,49
101	Uganda	51	4,69	13,60
102	Serbia	36	4,83	23,95
103	Tajikistan	34	4,84	15,86
104	Macau	39	4,84	8,40
105	Libya	13	4,87	10,79
106	Croatia	38	4,89	30,52
107	Czech Republic	22	4,91	8,78
108	Sint Maarten	26	4,92	19,35
109	Vanuatu	16	4,94	6,32
110	Guinea-Bissau	7	4,96	11,49
111	American Samoa	11	4,97	6,67
112	Honduras	16	5,02	10,00
113	Costa Rica	18	5,04	8,72
114	Algeria	21	5,15	25,22
115	Brunei Darussalam	9	5,25	14,81

Rank	Name	# Packages	Avg Cost 1GB (€)	Highest Cost 1GB (€)
116	Maldives	16	5,27	12,95
117	Colombia	57	5,28	15,93
118	Gambia	20	5,33	9,08
119	S.Tomé and Príncipe	19	5,33	15,34
120	Panama	29	5,56	8,33
121	Slovakia	32	5,56	33,92
122	Saudi Arabia	42	5,62	19,99
123	Congo	41	5,63	12,64
124	Sierra Leone	13	5,79	10,66
125	Gabon	10	5,84	13,26
126	Tanzania	40	5,93	53,76
127	Nth Mariana Islands	22	5,99	20,00
128	Central African R.	11	6,03	8,62
129	Nicaragua	32	6,04	19,59
130	Guadeloupe	9	6,06	15,83
131	Suriname	23	6,08	19,50
132	Paraguay	30	6,18	19,80
133	Somalia	24	6,19	16,67
134	Isle of Man	14	6,42	41,36
135	Hungary	18	6,56	10,97
136	United Kingdom	60	6,66	56,87
137	San Marino	6	6,86	9,19
138	Bahamas	16	6,89	11,19
139	Ecuador	18	6,93	20,00
140	Germany	58	6,96	22,60
141	Latvia	13	7,12	19,22
142	Bulgaria	26	7,15	37,54
143	South Africa	58	7,19	35,06
144	Barbados	35	7,21	18,52
145	Guyana	25	7,24	13,58
146	Mexico	57	7,38	34,63
147	Saint Barthélemy	17	7,40	21,48
148	Faroe Islands	7	7,77	33,19
149	Haiti	24	7,91	29,56
150	Angola	13	7,95	15,90
151	The Netherlands	41	7,99	37,69
152	Iraq	24	8,00	20,07
153	Palau	7	8,34	16,00
154	Japan	60	8,34	40,61
155	Solomon Islands	16	8,37	10,02
156	Martinique	30	8,46	33,92
157	Bolivia	28	8,51	20,66
158	Niue	10	9,20	28,00

Rank	**Name**	# Packages	Avg Cost 1GB (€)	Highest Cost 1GB (€)
159	Lebanon	20	9,21	20,00
160	Mali	15	9,22	22,75
161	Andorra	10	9,31	35,46
162	Taiwan	35	9,49	43,13
163	Caribb. Netherlands	34	9,57	35,00
164	Saint Lucia	25	9,78	22,16
165	New Zealand	42	9,79	35,49
166	China	28	9,89	26,61
167	Mayotte	8	10,18	33,90
168	United Arab Emir.	21	10,23	28,30
169	Svalbard	11	10,26	28,89
170	Saint-Martin	29	10,40	24,73
171	Namibia	24	11,02	26,80
172	Kiribati	22	11,05	21,34
173	Puerto Rico	21	11,12	25,00
174	Oman	38	11,28	25,98
175	Papua New Guinea	34	11,51	18,36
176	Grenada	20	11,56	29,60
177	A. and Barbuda	41	11,71	61,39
178	Togo	3	11,76	12,31
179	Saint Vincent	23	12,00	37,00
180	Canada	60	12,02	60,37
181	Swaziland	45	12,14	39,00
182	Belgium	60	12,30	101,77
183	United States	32	12,37	60,00
184	Curaçao	25	12,42	27,64
185	Comoros	10	12,57	22,92
186	Cuba	5	12,58	13,33
187	Aruba	22	12,70	22,21
188	Gibraltar	11	12,82	30,77
189	Micronesia	7	12,87	50,00
190	Guam	35	12,97	70,00
191	Virgin Islands (U.S.)	21	13,10	59,96
192	Norway	49	13,21	114,87
193	French Guiana	28	13,41	112,96
194	Liechtenstein	17	13,95	37,84
195	Portugal	25	13,98	67,79
196	Botswana	15	14,12	21,34
197	Dominica	25	14,60	29,60
198	Montserrat	17	14,61	33,30
199	Anguilla	23	14,90	37,00
200	Saint Kitts and Nevis	31	15,05	37,00
201	South Korea	15	15,12	34,02
202	Yemen	29	15,73	39,95
203	Mozambique	34	15,82	55,84
204	Greenland	3	16,79	22,65
205	New Caledonia	9	16,91	23,89
206	Trinidad and Tobago	7	17,10	29,52

Rank	Name	# Packages	Avg Cost 1GB (€)	Highest Cost 1GB (€)
207	Cook Islands	8	18,12	33,45
208	Virgin Islands	42	18,55	40,00
209	Malta	29	18,79	90,46
210	Seychelles	23	19,55	71,72
211	Turkmenistan	7	19,81	42,89
212	Switzerland	12	20,22	49,79
213	Cyprus	13	20,25	38,44
214	Benin	16	20,99	24,62
215	French Polynesia	14	21,64	49,29
216	Turks and Caicos Islands	26	23,09	46,67
217	Chad	10	23,33	68,94
218	Tonga	8	25,52	54,25
219	Cayman Islands	26	26,79	143,69
220	Wallis and Fortuna	6	26,86	47,40
221	Nauru	5	28,13	38,41
222	Tokelau	15	29,96	40,87
223	Samoa	42	30,09	253,43
224	Greece	15	32,71	106,85
225	Bermuda	25	37,74	100,01
226	Djibouti	5	37,92	112,54
227	Falkland Islands	4	47,39	77,55
228	Saint Helena	4	55,47	64,63
229	Equatorial Guinea	12	65,83	114,79
230	Zimbabwe	37	75,20	138,46

The data was retrieved from Cable.co.uk (2020b) and corresponds to data gathered during the year of 2018 and 2019.

Appendix C

Worldwide Wi-Fi Cost

The table is ranked from the cheapest average price (€) to the most expensive worldwide.

Table C.1: Worldwide Wi-Fi Package Cost (Cable.co.uk, 2020a)

Rank	**Name**	# Packages	Avg Cost Pack (€)	Highest Cost Pack (€)
1	Syria	41	6,60	63,05
2	Ukraine	14	6,64	13,00
3	Russian Federation	23	7,35	32,66
4	Romania	13	8,15	12,81
5	Belarus	14	9,87	19,74
6	Bhutan	1	10,42	10,42
7	Iran	35	10,50	25,80
8	Kazakhstan	18	11,10	52,58
9	Lithuania	18	11,14	23,60
10	Vietnam	9	11,23	33,26
11	Uzbekistan	23	11,44	64,11
12	Moldova	11	11,57	17,36
13	Nepal	30	12,05	63,00
14	Mongolia	14	12,59	29,85
15	India	32	12,90	56,48
16	Turkey	34	13,61	49,38
17	Argentina	24	13,69	46,74
18	Egypt	25	13,82	32,98
19	Georgia	23	13,86	36,08
20	Tunisia	38	14,28	72,76
21	Armenia	39	14,60	87,62
22	Poland	38	15,78	44,68
23	Bulgaria	17	15,93	78,14
24	Latvia	16	16,55	29,12
25	Azerbaijan	41	16,76	222,12
26	Hungary	16	16,91	42,98
27	Serbia	19	17,02	85,12
28	Pakistan	35	17,55	76,46

Rank	Name	# Packages	Avg Cost Pack (€)	Highest Cost Pack (€)
29	Slovakia	25	18,54	159,16
30	Israel	26	19,90	37,49
31	Northern Macedonia	16	20,11	65,57
32	B. and Herzegovina	38	20,19	131,72
33	Albania	18	20,55	47,18
34	Eswatini	9	21,73	277,44
35	Czechia	17	22,38	41,36
36	Réunion	5	22,45	40,61
37	Thailand	19	23,82	43,06
38	Paraguay	17	24,46	45,39
39	Saint Martin	7	24,65	40,15
40	Colombia	21	25,05	79,50
41	South Korea	18	25,52	44,36
42	Afghanistan	21	25,87	105,60
43	Algeria	4	25,93	66,11
44	Peru	8	26,17	37,67
45	Dominican Republic	22	26,52	288,29
46	Bangladesh	14	27,35	54,49
47	Taiwan	41	27,36	80,23
48	Sri Lanka	21	27,40	320,03
49	France	19	27,81	51,20
50	Brazil	18	28,24	58,02
51	Kyrgyzstan	15	28,70	71,04
52	Germany	41	28,74	225,37
53	Estonia	10	28,93	111,30
54	Indonesia	26	30,02	97,00
55	Montenegro	9	30,04	42,28
56	Slovenia	13	31,16	47,86
57	China	16	31,41	418,93
58	Malaysia	19	31,75	75,82
59	Palestine, State of	17	31,90	206,77
60	Cambodia	25	32,63	60,50
61	Andorra	3	32,65	40,44
62	Mayotte	6	32,78	58,32
63	Mexico	15	33,15	84,41
64	Italy	15	33,28	50,64
65	Croatia	13	33,69	71,75
66	Morocco	10	33,81	104,36
67	Chile	21	33,99	66,93
68	Monaco	9	34,49	55,54
69	Canada	36	34,86	118,82
70	Tajikistan	20	35,58	127,76
71	United Kingdom	36	35,71	71,33
72	Austria	16	35,99	169,26

Rank	Name	# Packages	Avg Cost Pack (€)	Highest Cost Pack (€)
73	St. Barts	5	36,34	58,23
74	Cape Verde	6	36,45	62,85
75	Myanmar	29	36,82	101,16
76	Macau	9	37,48	78,71
77	Guatemala	14	38,13	106,90
78	Senegal	1	38,82	38,82
79	New Caledonia	15	39,02	278,66
80	Philippines	26	39,29	189,93
81	Spain	20	39,38	91,81
82	Sweden	12	39,60	99,61
83	Suriname	2	39,82	49,24
84	Uruguay	20	40,10	69,61
85	Lebanon	20	40,14	176,97
86	Japan	32	40,33	69,36
87	Malta	11	40,33	68,17
88	Greece	20	40,56	103,51
89	Åland Islands	18	40,74	165,83
90	Iraq	6	41,49	51,08
91	Bolivia	32	41,53	132,80
92	El Salvador	12	41,96	75,00
93	The Netherlands	18	42,43	63,72
94	Grenada	5	42,55	57,35
95	Costa Rica	25	43,22	254,88
96	Singapore	9	43,80	140,30
97	Finland	10	43,85	63,44
98	Ecuador	33	43,87	319,20
99	Martinique	6	44,32	62,40
100	Belgium	16	44,39	84,13
101	South Africa	35	44,77	172,94
102	Togo	5	45,91	834,23
103	Gibraltar	6	46,13	67,66
104	French Guiana	6	47,05	66,67
105	Lao People’s	18	47,24	4386,95
106	Hong Kong	7	47,35	371,59
107	Panama	6	47,45	120,01
108	Jamaica	12	47,57	163,00
109	Puerto Rico	27	47,99	194,99
110	St. Pierre y Miquelon	4	48,04	61,21
111	Luxembourg	32	48,16	156,93
112	Denmark	34	48,23	81,04
113	Australia	31	48,35	90,94
114	Kuwait	40	48,89	201,06
115	San Marino	7	48,97	93,49
116	Cyprus	23	49,39	185,42
117	Portugal	13	49,42	63,89

Rank	Name	# Packages	Avg Cost Pack (€)	Highest Cost Pack (€)
118	Saint Lucia	3	49,95	59,20
119	United States	27	50,00	299,99
120	Mauritius	3	50,30	95,56
121	Papua New Guinea	10	51,06	1146,74
122	Dominica	3	51,43	68,45
123	Libya	9	51,97	121,86
124	Somalia	2	52,50	100,00
125	New Zealand	36	54,00	79,53
126	Guyana	6	54,66	80,28
127	Niger	6	55,07	220,39
128	Fiji	9	55,42	149,42
129	Kenya	19	56,11	221,51
130	Jordan	19	56,42	114,37
131	Nicaragua	12	56,50	114,00
132	Trinidad and Tobago	19	56,73	125,80
133	Ireland	15	57,32	98,86
134	Timor-Leste	1	57,33	57,33
135	Isle of Man	20	57,80	189,63
136	Angola	15	59,04	219,92
137	Mali	7	59,34	440,78
138	Benin	4	59,34	138,45
139	Barbados	9	59,46	299,79
140	Honduras	5	60,00	100,00
141	Cameroon	13	60,47	136,75
142	Guadeloupe	6	61,10	80,68
143	Guernsey	4	62,14	89,28
144	Belize	3	62,54	102,25
145	Zimbabwe	9	63,87	145,35
146	Iceland	13	64,71	96,78
147	Côte d'Ivoire	15	66,12	144,10
148	Aruba	3	66,95	102,50
149	Liechtenstein	11	66,99	92,75
150	Madagascar	2	67,21	67,21
151	Ghana	5	69,54	135,74
152	Norway	29	70,97	146,05
153	Ethiopia	12	71,15	230,34
154	Switzerland	28	72,10	153,55
155	Saint Helena	6	72,26	239,58
156	Sao Tome and Prencipe	7	74,00	295,75
157	Saint Kitts and Nevis	10	76,58	185,01
158	Gabon	14	77,91	263,48
159	Oman	11	77,91	228,55
160	Nigeria	13	78,21	168,00
161	Montserrat	6	78,43	129,14
162	Faroe Islands	13	78,49	91,37
163	Curaçao	18	78,57	202,99

Rank	**Name**	# Packages	Avg Cost Pack (€)	Highest Cost Pack (€)
164	Guam	3	79,00	86,75
165	French Polynesia	6	80,14	154,61
166	Caribbean Netherlands	4	80,89	90,89
167	Jersey	4	80,97	103,39
168	Micronesia	5	81,00	226,00
169	Antigua and Barbuda	8	82,14	129,14
170	Bahamas	10	82,56	254,30
171	Saudi Arabia	14	82,85	223,90
172	St Vincent	3	83,25	111,01
173	American Samoa	7	85,00	165,16
174	Virgin Islands (U.S.)	7	85,97	156,01
175	Marshall Islands	4	86,20	141,20
176	Maldives	16	88,53	170,73
177	Palau	2	89,98	119,95
178	Cook Islands	5	92,12	198,17
179	Lesotho	4	94,04	208,55
180	Djibouti	4	95,07	145,65
181	Vanuatu	10	95,25	368,76
182	Sint Maarten	8	95,44	305,53
183	Comoros	4	98,23	197,58
184	Anguilla	7	99,54	203,14
185	Qatar	11	109,87	412,00
186	Botswana	11	112,38	333,42
187	United Arab Emirates	7	115,97	318,94
188	Seychelles	8	122,72	629,56
189	Haiti	6	124,50	249,00
190	Bermuda	22	129,98	289,00
191	Namibia	16	133,38	440,78
192	Turks and Caicos Islands	9	134,99	224,99
193	Bahrain	18	145,89	795,78
194	Falkland Islands	7	147,74	611,42
195	Cayman Islands	11	150,07	306,15
196	Brunei Darussalam	15	157,02	750,95
197	Greenland	3	163,68	178,57
198	Mozambique	13	175,25	385,88
199	Virgin Islands (British)	4	179,00	299,00
200	Tanzania	20	188,16	1488,11
201	Turkmenistan	18	224,68	1197,55
202	Equatorial Guinea	5	259,38	652,69
203	Burundi	7	283,73	306,88
204	Mauritania	4	694,63	1333,78
205	Yemen	21	2466,67	8333,33
206	Eritrea	20	2666,24	15051,29

The data was retrieved from Cable.co.uk (2020a) and corresponds to data gathered during the year of 2019 and 2020.

Appendix D

Veniam's entire competitive landscape

Table D.1: Veniam's entire competitive landscape

Company	Product	Competition	Threat	Sector
Aeris Comm.	Platform: Aeris Mobility Suite	Direct	3	Telecomm.
Airbiquity	Software: Aibiquity OTAmatic	Direct	1	Automotive
Android Auto	Connectivity: Enables mobile applications in the vehicle dashboard	Indirect	0	Automotive
Atos	Software: Horus security suite for ITS	Direct	2	IT Tech
Automatic	App and hardware: Automatic	Partnership	2	Automotive
Automotive Grade Linux	Software: AGL Unified Code Base	Direct	1	Automotive
Autotalks	Hardware: CRATON2 and SECTON chipset	Indirect	0	Hardware
Bittium	Software: Automotive Software Development (solutions for OEMs and users)	Partnership	2	IoT Services
Carnegie Technologies	Platform: NCP (Network Convergence Platform)	Direct	4	IT Tech
Cerence	Moving Experience: voice apps and assistance	Partnership	0	AI
Cohda Wireless	Hardware: V2X Stack, MK5 OBU, MK5 RSU	Partnership	0	Hardware
Commsignia	Software: V2X Software Stack and Hardware: V2X units	Indirect	3	Automotive
Connected Cars	Hardware: Connected Cars Device and Software: Fleet Dashboard + Driver App	Partnership	2	Automotive

Company	Product	Competition	Threat	Sector
Cubic Telecom	Platform: Cubic Telecom Dashboard	Indirect	1	IoT Services
Elektrobit	Software: EB cadian Analytics + EB cadian Sync + EB's security solutions	Direct	2	Automotive
EnGIS	Software: Connected ADAS + OTA + Mobile Platform	Partnership	1	Automotive
ETAS	Software: ETAS AUTOSAR Solutions	Indirect	2	Automotive
Excelfore	Software: Data Platform + OTA Pipeline + In-vehicle Networks	Direct	1	Automotive
GlobeTouch/ Airlinq	Platform: Airlinq connectivity management suite	Partnership	2	Automotive
Green Hills Software	Platform: Secure Connected Car	Indirect	0	Software
Harman Connected Car	Platform: HARMAN Ignite Automotive Cloud	Partnership	2	Software
High Mobility	The Platform (customized as the user prefers - API and SDK based)	Partnership	1	Automotive
Huawei	Software: Huawei Connected Vehicle Solution	Partnership	2	Telecomm.
Infineon	Hardware: Automotive Security (gateway and Telematics Control Unit)	Partnership	0	Semiconductors
Infovista	Platform: TEMS™ for Connected Car	Direct	2	IT Tech
Intelematics	ASURE 24/7 Emergency Assistance	Indirect	1	IoT Services
Jasper Technologies	Platform: Cisco IoT Control Center	Indirect	2	IoT Services
Kymeta	Hardware: Kymeta System	Indirect.	1	Telecomm.
Marvell Technology	Hardware: Automotive Ethernet and automotive storage	Partnership	0	Hardware
Movimento Group	Platform: Movimento OTA Platform	Direct	3	Automotive
Nuvoton	Hardware: Chip Solutions for voice alerts, location and Human-machine interaction	Indirect	0	Hardware
NXP	Hardware: Automotive Telematics Box (T-box) for V2X	Indirect	0	IT Tech
Octo Telematics	Platform: Octo IoT platform	Partnership	2	Automotive

Company	Product	Competition	Threat	Sector
Omoove	Platform: Intelligent Mobility and Fleet Management and enhanced Vehicle Management and Hardware: OBU	Partnership	2	IT Tech
On Board Security	Software: Aerolink Security	Partnership	0	Software
Otonomo	Platform: Otonomo Automotive Data Services	Partnership	2	Automotive
PATEO	Hardware: Core Platform and Software: Vehicle Data	Partnership	1	AI
Peloton Technology	Platform: Network Operations Cloud	Partnership	2	Automotive
Radwin	Software & hardware: On-board Wi-Fi for passengers	Partnership	2	Telecomm.
Remoto	Platform:Remoto Platform (includes mobile app, hardware and OEMs portal) – previously Bright Box Company	Partnership	1	Automotive
Renesas	Platform: Renesas autonomy™	Indirect	1	Semiconductors
Savari	Software: Savari's Radio Agnostic and Hardware: RSU and OBU	Partnership	2	Automotive
Sibros	Platform: Connected Vehicle Suite	Partnership	2	Automotive
Sierra Wireless	Platform: Sierra Wireless' Legato embedded application	Partnership	1	IoT Services
Single Digits	Software: The Connected Life Experience™ (CLE)	Direct	3	IoT Services
Sprint	Platform: Sprint Curiosity IoT Platform	Indirect	1	Telecomm.
Targa Telematics	App: My Targa Fleet (fleet management on the move)	Partnership	2	IT Tech
Tesla	Connectivity: End user Applications	Indirect	2	Automotive
Wejo	Platform: wejo ADEPT	Direct	2	Automotive
Western Digital	Hardware: Flash storage solutions	Partnership	0	Hardware
WindRiver	Software: WindRiver Edge Sync	Direct	2	Hardware
Wireless Car	Connectivity: services creation	Partnership	1	Automotive
Xevo	Platform: Xevo Market	Partnership	0	Software
Yogoko	Software & Hardware: Yogoko Communication System (Y-BOX, Y-SMART,Y-CLOUD)	Direct	3	IT Tech

Appendix E

Complete Simulation Results

E.1 Results of E1 for 100MB file with 10 repetitions

Table E.1: Results of Experiment 1 for 100MB file with 10 repetitions

E1 100MB 10 repetitions									
PFPS (%)	Nseeder	Seeding Strategy	Chunk Size (MB)	Seeded (%)	**Offloaded (%)**	STDEV (%)	Confidence level (%)	**Confidence Interval (%)**	Aposteriori (%)
100%	1	FCFS	1	0.3	86.41	N/A	N/A	N/A	13.29
			5	0.3	41.74	N/A	N/A	N/A	57.96
			10	0.3	4.85	N/A	N/A	N/A	94.85
		Random	1	0.3	72.31	28.10	17.42	72.31± 17.42	27.39
			5	0.3	46.25	22.02	13.65	46.25± 13.65	53.45
			10	0.3	15.61	10.20	6.32	15.61± 6.32	84.09
		Weigthed	1	0.3	86.87	1.03	0.64	86.87± 0.64	12.83
			5	0.3	58.26	10.96	6.79	58.26± 6.79	41.44
			10	0.3	20.97	8.88	5.50	20.97± 5.50	78.73
50%	2	FCFS	1	0.3	45.65	N/A	N/A	N/A	54.05
			5	0.3	36.08	N/A	N/A	N/A	63.62
			10	0.3	4.63	N/A	N/A	N/A	95.07
		Random	1	0.3	64.97	7.29	4.52	64.97± 4.52	34.73
			5	0.3	54.01	8.57	5.31	54.01± 5.31	45.69
			10	0.3	24.50	9.37	5.81	24.50± 5.81	75.20
		Weigthed	1	0.3	66.43	4.94	3.06	66.43± 3.06	33.27
			5	0.3	54.31	6.32	3.92	54.31± 3.92	45.39
			10	0.3	24.63	6.29	3.90	24.63± 3.90	75.07
25%	4	FCFS	1	0.3	53.48	N/A	N/A	N/A	46.22
			5	0.3	48.11	N/A	N/A	N/A	51.59
			10	0.2	20.89	N/A	N/A	N/A	78.91
		Random	1	0.3	57.32	8.81	5.46	57.32± 5.46	42.38
			5	0.3	52.38	7.47	4.63	52.39± 4.63	47.32
			10	0.2	25.28	5.70	3.54	25.28± 3.54	74.52
		Weigthed	1	0.3	61.22	2.70	1.67	61.22± 1.67	38.48
			5	0.3	54.86	5.18	3.21	54.86± 3.21	44.84
			10	0.2	28.78	4.10	2.54	28.78± 2.54	71.02
20%	5	FCFS	1	0.3	54.16	N/A	N/A	N/A	45.54
		Random		0.3	57.48	6.85	4.24	57.48± 4.24	42.22
		Weighted		0.3	60.09	2.95	1.83	60.09± 1.83	39.61
10%	10	FCFS	1	0.3	55.18	N/A	N/A	N/A	44.52
		Random		0.3	55.46	3.71	2.30	55.46± 2.30	44.24
		Weighted		0.3	59.35	4.27	2.65	59.35± 2.65	40.35
5%	20	FCFS	1	0.3	57.41	N/A	N/A	N/A	42.29
		Random		0.3	56.57	2.78	1.72	56.57± 1.72	43.13
		Weighted		0.3	59.15	2.73	1.69	59.15± 1.69	40.55

PFPS (%)	Nseeder	Seeding Strategy	Chunk Size (MB)	Seeded (%)	**Offloaded (%)**	STDEV (%)	Confidence level (%)	**Confidence Interval (%)**	Aposteriori (%)
4%	25	FCFS Random Weighted	1	0.3 0.3 0.3	57.67 56.60 58.65	N/A 2.56 2.42	N/A 1.58 1.50	N/A 56.60± 1.58 58.65± 1.50	42.03 43.10 41.05
2%	50	FCFS Random Weighted	1	0.3 0.3 0.3	55.51 54.55 56.30	N/A 2.04 1.35	N/A 1.26 0.83	N/A 54.55± 1.26 56.30± 0.83	44.19 45.15 43.40
1%	100	FCFS Random Weighted	1	0.3 0.3 0.3	56.86 55.85 56.99	N/A 3.98 3.65	N/A 2.47 2.26	N/A 55.85± 2.47 56.99± 2.26	42.84 43.85 42.71

E.2 Results of Experiment 1 for 100MB file with 20 repetitions

Table E.2: Results of Experiment 1 for 100MB file with 20 repetitions

E1 100MB 20 repetitions									
PFPS (%)	Nseeder	Seeding Strategy	Chunk Size (MB)	Seeded (%)	**Offloaded (%)**	STDEV (%)	Confidence level (%)	**Confidence Interval (%)**	Aposteriori (%)
100%	1	FCFS Random Weigthed	1 1 1	0.3 0.3 0.3	86.44 70.01 79.52	N/A 29.72 17.39	N/A 13.03 7.62	N/A 70.01± 13.03 79.52± 7.62	13.26 29.69 20.18
50%	2	FCFS Random Weigthed	1 1 1	0.3 0.3 0.3	45.62 64.12 65.94	N/A 6.70 3.97	N/A 2.94 1.74	N/A 64.12± 2.94 65.94± 1.74	54.08 35.58 33.77
25%	4	FCFS Random Weigthed	1 1 1	0.3 0.3 0.3	53.05 58.40 60.73	N/A 6.68 2.30	N/A 2.93 1.01	N/A 58.40± 2.93 60.73± 1.01	46.65 41.30 38.97
20%	5	FCFS Random Weighted	1 1 1	0.3 0.3 0.3	54.28 58.39 60.28	N/A 5.38 2.41	N/A 2.36 1.06	N/A 58.39± 2.36 60.28± 1.06	45.42 41.31 39.42
10%	10	FCFS Random Weighted	1 1 1	0.3 0.3 0.3	55.98 57.87 59.87	N/A 3.87 3.41	N/A 1.70 1.50	N/A 57.87± 1.70 59.87± 1.50	43.72 41.83 39.83
5%	20	FCFS Random Weighted	1 1 1	0.3 0.3 0.3	57.02 56.92 58.70	N/A 3.07 2.73	N/A 1.35 1.20	N/A 56.92± 1.35 58.70± 1.20	42.68 42.78 41.00
4%	25	FCFS Random Weighted	1 1 1	0.3 0.3 0.3	56.94 56.22 58.07	N/A 3.92 3.90	N/A 1.72 1.71	N/A 56.22± 1.72 58.07± 1.71	42.76 43.48 41.63
2%	50	FCFS Random Weighted	1 1 1	0.3 0.3 0.3	55.90 55.13 56.65	N/A 2.51 2.19	N/A 1.10 0.96	N/A 55.13± 1.10 56.65± 0.96	43.80 44.57 43.05
1%	100	FCFS Random Weighted	1 1 1	0.3 0.3 0.3	56.57 55.47 56.81	N/A 3.52 3.14	N/A 1.54 1.38	N/A 55.47± 1.54 56.81± 1.38	43.13 44.23 42.89

E.3 Results of Experiment 1 for 1GB file with 10 repetitions

Table E.3: Results of Experiment 1 for 1GB file with 10 repetitions

E1 1GB 10 repetitions									
PFPS (%)	Nseeder	Seeding Strategy	Chunk Size (MB)	Seeded (%)	**Offloaded (%)**	STDEV (%)	Confidence level (%)	**Confidence Interval (%)**	Aposteriori (%)
100%	1	FCFS	1	0.3	13.62	0.09	0.06	13.62± 0.06	86.08
		Random	1	0.3	12.67	6.48	4.02	12.67± 4.02	87.03
		Weighted	1	0.3	17.02	2.06	1.28	17.02± 1.28	82.68
50%	2	FCFS	1	0.3	13.37	0.19	0.12	13.37± 0.12	86.33
		Random	1	0.3	19.28	2.91	1.80	19.28± 1.80	80.42
		Weighted	1	0.3	20.10	1.83	1.13	20.11± 1.13	79.60
25%	4	FCFS	1	0.3	21.37	0.10	0.06	21.37± 0.06	78.33
		Random	1	0.3	22.28	1.67	1.03	22.29± 1.03	77.42
		Weighted	1	0.3	23.46	0.92	0.57	23.46± 0.57	76.24
20%	5	FCFS	1	0.3	23.92	0.10	0.06	23.92± 0.06	75.78
		Random	1	0.3	23.59	1.30	0.80	23.59± 0.80	76.11
		Weighted	1	0.3	24.06	0.65	0.40	24.06± 0.40	75.64
12.50%	8	FCFS	1	0.3	24.48	0.08	0.05	24.48± 0.05	75.22
		Random	1	0.3	24.65	1.18	0.73	24.65± 0.73	75.05
		Weighted	1	0.3	25.50	0.36	0.22	25.50± 0.22	74.20
10%	10	FCFS	1	0.3	25.12	0.10	0.06	25.12± 0.06	74.58
		Random	1	0.3	24.98	1.02	0.63	24.98± 0.63	74.72
		Weighted	1	0.3	25.98	0.28	0.17	25.98± 0.17	73.72
5%	20	FCFS	1	0.3	26.52	0.06	0.04	26.52± 0.04	73.18
		Random	1	0.3	26.21	0.58	0.36	26.21± 0.36	73.49
		Weighted	1	0.3	26.85	0.28	0.17	26.85± 0.17	72.85
4%	25	FCFS	1	0.3	26.66	0.07	0.04	26.66± 0.04	73.04
		Random	1	0.3	26.46	0.46	0.28	26.46± 0.28	73.24
		Weighted	1	0.3	27.01	0.27	0.17	27.01± 0.17	72.69
2.50%	40	FCFS	1	0.3	27.40	0.05	0.03	27.40± 0.03	72.30
		Random	1	0.3	27.02	0.27	0.17	27.02± 0.17	72.68
		Weighted	1	0.3	27.54	0.17	0.11	27.54± 0.11	72.16
2%	50	FCFS	1	0.3	27.65	0.11	0.07	27.65± 0.07	72.05
		Random	1	0.3	27.19	0.17	0.10	27.19± 0.10	72.51
		Weighted	1	0.3	27.69	0.21	0.13	27.69± 0.13	72.01
1%	100	FCFS	1	0.3	28.24	0.08	0.05	28.25± 0.05	71.45
		Random	1	0.3	27.76	0.12	0.07	27.76± 0.07	71.94
		Weighted	1	0.3	28.13	0.13	0.08	28.13± 0.08	71.57
0.80%	125	FCFS	1	0.3	28.41	0.08	0.05	28.42± 0.05	71.29
		Random	1	0.3	27.87	0.12	0.07	27.87± 0.07	71.83
		Weighted	1	0.3	28.25	0.10	0.06	28.25± 0.06	71.45
0.50%	200	FCFS	1	0.3	28.65	0.06	0.04	28.65± 0.04	71.05
		Random	1	0.3	28.10	0.05	0.03	28.10± 0.03	71.60
		Weighted	1	0.3	28.49	0.05	0.03	28.49± 0.03	71.21
0.40%	250	FCFS	1	0.3	28.68	0.07	0.04	28.68± 0.04	71.02
		Random	1	0.3	28.20	0.06	0.04	28.20± 0.04	71.50
		Weighted	1	0.3	28.53	0.07	0.04	28.53± 0.04	71.17

E.4 Results of Experiment 1 for 1GB file with 20 repetitions

Table E.4: Results of Experiment 1 for 1GB file with 20 repetitions

E1 1GB 20 repetitions									
PFPS (%)	Nseeder	Seeding Strategy	Chunk Size (MB)	Seeded (%)	**Offloaded (%)**	STDEV (%)	Confidence level (%)	**Confidence Interval (%)**	Aposteriori (%)
100%	1	FCFS	1	0.3	13.59	N/A	N/A	N/A	86.11
		Random	1	0.3	12.15	6.51	2.85	12.15± 2.85	87.55
		Weighted	1	0.3	14.48	4.95	2.17	14.48± 2.17	85.22
50%	2	FCFS	1	0.3	13.37	N/A	N/A	N/A	86.33
		Random	1	0.3	19.50	2.69	1.18	19.50± 1.18	80.20
		Weighted	1	0.3	19.69	2.72	1.19	19.69± 1.19	80.02
25%	4	FCFS	1	0.3	21.41	N/A	N/A	N/A	78.29
		Random	1	0.3	22.41	1.59	0.70	22.41± 0.70	77.29
		Weighted	1	0.3	22.84	1.56	0.68	22.84± 0.68	76.86
20%	5	FCFS	1	0.3	23.89	N/A	N/A	N/A	75.81
		Random	1	0.3	23.52	1.10	0.48	23.52± 0.48	76.18
		Weighted	1	0.3	23.81	0.94	0.41	23.81± 0.41	75.89
12.5%	8	FCFS	1	0.3	24.46	N/A	N/A	N/A	75.24
		Random	1	0.3	24.69	0.96	0.42	24.69± 0.42	75.01
		Weighted	1	0.3	25.16	0.62	0.27	25.16± 0.27	74.54
10%	10	FCFS	1	0.3	25.13	N/A	N/A	N/A	74.58
		Random	1	0.3	25.09	0.90	0.39	25.09± 0.39	74.61
		Weighted	1	0.3	25.63	0.57	0.25	25.63± 0.25	74.07
5%	20	FCFS	1	0.3	26.54	N/A	N/A	N/A	73.16
		Random	1	0.3	26.22	0.45	0.20	26.22± 0.20	73.48
		Weighted	1	0.3	26.72	0.30	0.13	26.72± 0.13	72.98
4%	25	FCFS	1	0.3	26.66	N/A	N/A	N/A	73.04
		Random	1	0.3	26.46	0.41	0.18	26.46± 0.18	73.24
		Weighted	1	0.3	26.94	0.24	0.10	26.94± 0.10	72.76
2.5%	40	FCFS	1	0.3	27.36	N/A	N/A	N/A	72.34
		Random	1	0.3	27.01	0.23	0.10	27.01± 0.10	72.69
		Weighted	1	0.3	27.47	0.20	0.09	27.47± 0.09	72.23
2%	50	FCFS	1	0.3	27.68	N/A	N/A	N/A	72.02
		Random	1	0.3	27.19	0.20	0.09	27.19± 0.09	72.51
		Weighted	1	0.3	27.67	0.18	0.08	27.67± 0.08	72.03
1%	100	FCFS	1	0.3	28.25	N/A	N/A	N/A	71.45
		Random	1	0.3	27.71	0.14	0.06	27.71± 0.06	71.99
		Weighted	1	0.3	28.12	0.12	0.05	28.12± 0.05	71.58
0.8%	125	FCFS	1	0.3	28.41	N/A	N/A	N/A	71.29
		Random	1	0.3	27.83	0.13	0.06	27.83± 0.06	71.87
		Weighted	1	0.3	28.22	0.10	0.04	28.22± 0.04	71.48
0.5%	200	FCFS	1	0.3	28.64	N/A	N/A	N/A	71.06
		Random	1	0.3	28.07	0.07	0.03	28.07± 0.03	71.63
		Weighted	1	0.3	28.44	0.08	0.03	28.44± 0.03	71.26
0.4%	250	FCFS	1	0.3	28.66	N/A	N/A	N/A	71.04
		Random	1	0.3	28.18	0.08	0.04	28.18± 0.04	71.52
		Weighted	1	0.3	28.49	0.10	0.04	28.49± 0.04	71.21

E.5 Results of Experiment 2 for 100MB file with 10 repetitions

Table E.5: Results of Experiment 2 for 100MB file with 10 repetitions

E2 100MB 10 repetitions							
Nseeder	PFPS (%)	Seeded (%)	**Offloaded (%)**	STDEV (%)	Confidence level (%)	**Confidence Interval (%)**	Aposteriori (%)
1	100%	0.3	72.31	28.10	17.42	72.31± 17.42	27.39
2	50%	0.3	64.97	7.29	4.52	64.97± 4.52	34.73
	64%	0.4	74.64	6.47	4.01	74.64± 4.01	24.96
	100%	0.6	87.60	1.21	0.75	87.60± 0.75	11.80
4	25%	0.3	57.32	8.81	5.46	57.32± 5.46	42.38
	32%	0.4	65.52	8.55	5.30	65.52± 5.30	34.08
	64%	0.7	85.03	3.57	2.21	85.04± 2.21	14.27
	100%	1.1	87.89	0.45	0.28	87.89± 0.28	11.01
5	20%	0.3	57.48	6.85	4.24	57.48± 4.24	42.22
	32%	0.4	73.15	6.80	4.22	73.15± 4.22	26.45
	64%	0.9	87.42	0.63	0.39	87.42± 0.39	11.68
	100%	1.4	87.86	0.47	0.29	87.86± 0.29	10.74
10	10%	0.3	55.46	3.71	2.30	55.46± 2.30	44.24
	16%	0.4	72.17	3.25	2.02	72.17± 2.02	27.43
	32%	0.9	85.78	1.82	1.13	85.78± 1.13	13.32
	64%	1.8	87.89	0.31	0.19	87.89± 0.19	10.31
	100%	2.8	87.02	0.40	0.25	87.02± 0.25	10.19
20	5%	0.3	56.57	2.78	1.72	56.57± 1.72	43.13
	8%	0.4	71.92	4.13	2.56	71.92± 2.56	27.68
	16%	0.9	85.14	1.61	1.00	85.14± 1.00	13.96
	32%	1.8	88.02	0.26	0.16	88.02± 0.16	10.18
	64%	3.6	86.46	0.38	0.24	86.46± 0.24	9.94
	100%	5.6	84.61	0.50	0.31	84.61± 0.31	9.79
25	4%	0.3	56.60	2.56	1.58	56.60± 1.58	43.10
	8%	0.6	76.75	3.33	2.07	76.75± 2.07	22.65
	16%	1.1	86.69	1.29	0.80	86.69± 0.80	12.21
	32%	2.2	87.72	0.19	0.12	87.72± 0.12	10.08
	64%	4.5	85.75	0.30	0.19	85.75± 0.19	9.75
	100%	7	83.46	0.42	0.26	83.46± 0.26	9.54
50	2%	0.3	54.55	2.04	1.26	54.55± 1.26	45.15
	4%	0.6	77.46	2.14	1.33	77.46± 1.33	21.94
	8%	1.1	86.78	1.40	0.87	86.78± 0.87	12.12
	16%	2.2	87.96	0.11	0.07	87.96± 0.07	9.84
	32%	4.5	86.28	0.68	0.42	86.28± 0.42	9.22
	64%	9	82.10	0.30	0.19	82.10± 0.19	8.90
	100%	14	77.46	0.45	0.28	77.46± 0.28	8.54
100	1%	0.3	55.85	3.98	2.47	55.85± 2.47	43.85
	2%	0.6	75.46	3.81	2.36	75.46± 2.36	23.94
	4%	1.1	86.84	0.99	0.62	86.84± 0.62	12.06
	8%	2.2	87.75	0.45	0.28	87.75± 0.28	10.05
	16%	4.5	86.26	0.11	0.07	86.26± 0.07	9.24
	32%	9	82.36	0.17	0.11	82.36± 0.11	8.64
	64%	18	74.28	0.29	0.18	74.28± 0.18	7.72
	100%	28.1	64.87	0.44	0.27	64.87± 0.27	7.03

The seeding strategy for Experiment 2 is the Random, while the chunk size is 1MB, both for 100MB and 1GB file sizes.

E.6 Results of Experiment 2 for 1GB file with 10 repetitions

Table E.6: Results of Experiment 2 for 1GB file with 10 repetitions

			E2 1GB 10 repetitions				
Nseeder	PFPS (%)	Seeded (%)	**Offloaded (%)**	STDEV (%)	Confidence level (%)	**Confidence Interval (%)**	Aposteriori (%)
1	100%	0.30	12.67	6.48	4.02	12.67± 4.02	87.03
2	50%	0.30	19.28	2.91	1.80	19.28± 1.80	80.42
	51.20%	0.30	19.32	2.82	1.75	19.32± 1.75	80.38
	64%	0.40	19.43	2.87	1.78	19.43± 1.78	80.17
	100%	0.60	19.69	2.94	1.83	19.69± 1.83	79.71
4	25%	0.30	22.28	1.67	1.03	22.29± 1.03	77.42
	25.60%	0.30	22.35	1.66	1.03	22.35± 1.03	77.35
	32%	0.40	22.67	1.46	0.90	22.67± 0.90	76.93
	51.20%	0.60	22.98	1.37	0.85	22.99± 0.85	76.42
	64%	0.70	23.07	1.38	0.85	23.07± 0.85	76.23
	100%	1.10	23.19	1.28	0.79	23.19± 0.79	75.71
5	20%	0.3	23.59	1.30	0.80	23.59± 0.80	76.11
	25.60%	0.40	23.88	1.21	0.75	23.88± 0.75	75.72
	32%	0.40	24.13	1.15	0.71	24.13± 0.71	75.47
	51.20%	0.70	24.32	1.12	0.69	24.32± 0.69	74.98
	64%	0.90	24.41	1.11	0.69	24.41± 0.69	74.69
	100%	1.40	24.36	1.06	0.65	24.36± 0.65	74.24
8	12.5%	0.30	24.65	1.18	0.73	24.65± 0.73	75.05
	12.80%	0.30	24.71	1.16	0.72	24.71± 0.72	74.99
	16%	0.40	25.08	1.03	0.64	25.08± 0.64	74.52
	25.60%	0.60	25.54	0.89	0.55	25.54± 0.55	73.86
	32%	0.70	25.65	0.87	0.54	25.65± 0.54	73.65
	51.20%	1.20	25.77	0.86	0.54	25.77± 0.54	73.03
	64%	1.40	25.77	0.82	0.51	25.77± 0.51	72.83
	100%	2.20	25.57	0.76	0.47	25.57± 0.47	72.23
10	10%	0.3	24.98	1.02	0.63	24.98± 0.63	74.72
	12.80%	0.40	25.46	0.95	0.59	25.46± 0.59	74.14
	16%	0.40	25.72	0.93	0.57	25.72± 0.57	73.88
	25.60%	0.70	26.07	0.89	0.55	26.07± 0.55	73.23
	32%	0.90	26.16	0.83	0.52	26.16± 0.52	72.94
	51.20%	1.40	26.19	0.82	0.51	26.19± 0.51	72.41
	64%	1.80	26.18	0.81	0.50	26.18± 0.50	72.02
	100%	2.80	25.82	0.75	0.46	25.83± 0.46	71.38
20	5%	0.30	26.21	0.58	0.36	26.21± 0.36	73.49
	6.40%	0.40	26.73	0.56	0.35	26.73± 0.35	72.87
	8%	0.40	27.08	0.55	0.34	27.08± 0.34	72.52
	12.80%	0.70	27.45	0.56	0.35	27.45± 0.35	71.85
	16%	0.90	27.55	0.57	0.35	27.55± 0.35	71.55
	25.60%	1.40	27.65	0.56	0.34	27.65± 0.34	70.95
	32%	1.80	27.66	0.56	0.34	27.66± 0.34	70.54
	51.20%	2.90	27.54	0.55	0.34	27.54± 0.34	69.56
	64%	3.60	27.38	0.55	0.34	27.38± 0.34	69.02
	100%	5.60	26.33	0.62	0.39	26.33± 0.39	68.07
25	4%	0.3	26.46	0.46	0.28	26.46± 0.28	73.24
	6.40%	0.40	27.41	0.44	0.27	27.41± 0.27	72.19
	8%	0.60	27.66	0.46	0.29	27.66± 0.29	71.74
	12.80%	0.90	27.95	0.44	0.27	27.95± 0.27	71.15
	16%	1.10	28.01	0.42	0.26	28.01± 0.26	70.89
	25.60%	1.80	28.07	0.44	0.28	28.07± 0.28	70.13
	32%	2.20	28.06	0.46	0.28	28.06± 0.28	69.74
	51.20%	3.60	27.91	0.48	0.30	27.91± 0.30	68.49
	64%	4.50	27.68	0.49	0.31	27.68± 0.31	67.82
	100%	7.00	26.33	0.61	0.38	26.33± 0.38	66.67

Nseeder	PFPS (%)	Seeded (%)	**Offloaded (%)**	STDEV (%)	Confidence level (%)	**Confidence Interval (%)**	Aposteriori (%)
40	2.5%	0.3	27.02	0.27	0.17	27.02± 0.17	72.68
	4%	0.40	28.03	0.27	0.16	28.03± 0.16	71.57
	6.40%	0.70	28.53	0.29	0.18	28.53± 0.18	70.77
	8%	0.90	28.68	0.30	0.18	28.68± 0.18	70.42
	12.80%	1.40	28.82	0.31	0.19	28.82± 0.19	69.78
	16%	1.80	28.85	0.32	0.20	28.85± 0.20	69.35
	25.60%	2.90	28.85	0.31	0.19	28.85± 0.19	68.25
	32%	3.60	28.81	0.32	0.20	28.81± 0.20	67.59
	51.20%	5.80	28.54	0.34	0.21	28.54± 0.21	65.66
	64%	7.20	28.20	0.37	0.23	28.20± 0.23	64.60
	100%	11.20	25.94	0.53	0.33	25.94± 0.33	62.86
50	2%	0.3	27.19	0.17	0.10	27.19± 0.10	72.51
	3.20%	0.40	28.25	0.16	0.10	28.25± 0.10	71.35
	4%	0.60	28.53	0.18	0.11	28.53± 0.11	70.87
	6.40%	0.90	28.91	0.20	0.12	28.91± 0.12	70.19
	8%	1.10	29.02	0.20	0.12	29.02± 0.12	69.88
	12.80%	1.80	29.14	0.22	0.13	29.14± 0.13	69.06
	16%	2.20	29.16	0.20	0.13	29.16± 0.13	68.64
	25.60%	3.60	29.13	0.21	0.13	29.13± 0.13	67.27
	32%	4.50	29.08	0.20	0.12	29.08± 0.12	66.42
	51.20%	7.20	28.73	0.25	0.16	28.73± 0.16	64.07
	64%	9.00	28.30	0.32	0.20	28.30± 0.20	62.70
	100%	25.10	25.33	0.47	0.29	25.33± 0.29	49.57
100	1%	0.30	27.76	0.12	0.07	27.76± 0.07	71.94
	1.60%	0.40	28.91	0.09	0.06	28.91± 0.06	70.69
	2%	0.60	29.23	0.07	0.05	29.23± 0.05	70.17
	3.20%	0.90	29.71	0.08	0.05	29.71± 0.05	69.39
	4%	1.10	29.86	0.08	0.05	29.86± 0.05	69.04
	6.40%	1.80	30.04	0.10	0.06	30.05± 0.06	68.16
	8%	2.20	30.10	0.10	0.06	30.10± 0.06	67.70
	12.80%	3.60	30.16	0.10	0.06	30.16± 0.06	66.24
	16%	4.50	30.15	0.11	0.07	30.15± 0.07	65.35
	25.60%	7.20	30.04	0.10	0.06	30.04± 0.06	62.76
	32%	9.00	29.92	0.10	0.06	29.92± 0.06	61.08
	51.20%	14.40	29.26	0.17	0.11	29.26± 0.11	56.34
	64%	18.00	28.34	0.29	0.18	28.34± 0.18	53.66
	100.00%	28.10	21.91	0.50	0.31	21.91± 0.31	49.99
125	0.80%	0.3	27.87	0.12	0.07	27.87± 0.07	71.83
	1.00%	0.40	28.52	0.10	0.06	28.52± 0.06	71.08
	1.60%	0.60	29.40	0.08	0.05	29.40± 0.05	70.00
	2.00%	0.70	29.68	0.07	0.05	29.68± 0.05	69.62
	3.20%	1.10	30.09	0.07	0.04	30.09± 0.04	68.81
	4.00%	1.40	30.23	0.07	0.04	30.23± 0.04	68.37
	6.40%	2.20	30.41	0.07	0.04	30.41± 0.04	67.39
	8.00%	2.80	30.47	0.07	0.04	30.47± 0.04	66.73
	12.80%	4.50	30.52	0.08	0.05	30.52± 0.05	64.98
	16.00%	5.60	30.51	0.07	0.04	30.51± 0.04	63.90
	25.60%	9.00	30.37	0.09	0.05	30.37± 0.05	60.63
	32.00%	11.20	30.22	0.09	0.06	30.22± 0.06	58.58
	51.20%	18.00	29.44	0.21	0.13	29.44± 0.13	52.56
	64.00%	22.50	28.30	0.33	0.21	28.30± 0.21	49.20
	100.00%	35.10	20.10	0.55	0.34	20.10± 0.34	44.80

Nseeder	PFPS (%)	Seeded (%)	**Offloaded (%)**	STDEV (%)	Confidence level (%)	**Confidence Interval (%)**	Aposteriori (%)
200	0.5%	0.3	28.10	0.05	0.03	28.10± 0.03	71.60
	0.80%	0.4	29.32	0.06	0.04	29.32± 0.04	70.28
	1.00%	0.60	29.72	0.06	0.03	29.72± 0.03	69.68
	1.60%	0.90	30.31	0.04	0.03	30.31± 0.03	68.79
	2.00%	1.10	30.51	0.04	0.02	30.51± 0.02	68.39
	3.20%	1.80	30.86	0.04	0.03	30.86± 0.03	67.34
	4.00%	2.20	30.98	0.06	0.03	30.98± 0.03	66.82
	6.40%	3.60	31.17	0.07	0.04	31.17± 0.04	65.23
	8.00%	4.50	31.24	0.07	0.04	31.24± 0.04	64.26
	12.80%	7.20	31.30	0.08	0.05	31.30± 0.05	61.50
	16.00%	9.00	31.27	0.08	0.05	31.27± 0.05	59.73
	25.60%	14.40	31.07	0.10	0.06	31.07± 0.06	54.53
	32.00%	18.00	30.86	0.11	0.07	30.86± 0.07	51.14
	51.20%	28.80	29.62	0.23	0.14	29.62± 0.14	41.58
	64.00%	36.00	27.76	0.34	0.21	27.76± 0.21	36.24
	100.00%	56.20	14.12	0.51	0.32	14.12± 0.32	29.68
250	0.40%	0.30	28.20	0.06	0.04	28.20± 0.04	71.50
	0.80%	0.60	29.84	0.05	0.03	29.84± 0.03	69.56
	1%	0.70	30.17	0.04	0.02	30.17± 0.02	69.13
	1.60%	1.10	30.71	0.03	0.02	30.72± 0.02	68.19
	2%	1.40	30.90	0.03	0.02	30.90± 0.02	67.70
	3.20%	2.20	31.23	0.04	0.03	31.23± 0.03	66.57
	4%	2.80	31.36	0.04	0.03	31.37± 0.03	65.84
	6.40%	4.50	31.57	0.06	0.04	31.57± 0.04	63.93
	8%	5.60	31.64	0.07	0.04	31.64± 0.04	62.76
	12.80%	9.00	31.69	0.08	0.05	31.69± 0.05	59.31
	16%	11.20	31.66	0.08	0.05	31.66± 0.05	57.14
	25.60%	18.00	31.44	0.10	0.06	31.44± 0.06	50.56
	32%	22.50	31.20	0.11	0.07	31.20± 0.07	46.30
	51.20%	36.00	29.64	0.22	0.13	29.65± 0.13	34.36
	64%	44.90	27.29	0.36	0.22	27.29± 0.22	27.81
	100.00%	70.20	9.92	0.43	0.26	9.92± 0.26	19.88