The best master's thesis ever

First Author
Second Author

Preface

I would like to thank everybody who kept me busy the last year, especially my promoter and my assistants. I would also like to thank the jury for reading the text. My sincere gratitude also goes to my wive and the rest of my family.

First Author
Second Author

Contents

Abstract

The `abstract` environment contains a more extensive overview of the work. But it should be limited to one page.

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List of Figures and Tables

List of Figures

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List of Abbreviations and Symbols

Abbreviations

LoG   Laplacian-of-Gaussian
MSE   Mean Square error
PSNR   Peak Signal-to-Noise ratio

Symbols

42   "The Answer to the Ultimate Question of Life, the Universe, and Everything" according to [**?**]
c Speed of light
E Energy
m Mass
π The number pi

Chapter 1

Introduction

The first contains a general introduction to the work. The goals are defined and the modus operandi is explained.

1.1 The problem

TEEs can be used for

1.2 Paper outline

- Schetsing van het probleem: Wat is het probleem, wat zijn de extra moeilijkheden ivm IoT, OTA update security schetsen in wijdere wereld van IoT security

- Beschrijving van huidige literatuur en verwante security oplossingen

- Hoog-level beschrijving van oplossing, technisch

- Implementatie mbv board

1.3 Trusted Execution Environments: A Technical Overview of Intel SGX, Arm TrustZone, and RISC-V PMP

video link

Def van TEE: Environment die 3 zaken verzekert: Data confidentiality, data integrity en code integrity

Mogelijke dingen die TEEs providen: Code confidentiality, Authenticated launch, programmability, attestability & recoverability

Belang voor thesis:

- Code confidentiality en attestability: Zeker zijn dat TEE secure is

- Programmability: Yesh

- Recoverability: Als de state van de TEE corrupt is, is het mogelijk deze te resetten naar een goede state

Attestation in depth: Attestation = integriteit van de TEE verzekeren. Hiervoor is een hardware root of trust nodig. Mbv symmetrische keys (lokaal) of asymmetrische keys (remote).
Arm Privilege levels

- EL-0, Application Privilege Level

- EL-1, Kernel Privilege Level

- EL-2, Virtualization Privilege Level (Optional)

- EL-3, Secure Privilege Level

Arm Trustzone explanation: Voor ARMv8-A architectuur en TrustZone implementaties provided door Arm's Trusted Firmware-A (TF-A) en Open-source Portable TEE (OP-TEE).
Arm SoC (System on a Chip) processors create separation between SW and NW using the Secure Configuration Register (SCR) "Non-Secure Bit", where 1 = non-secure and 0 = secure.
This separation of worlds is accomplished using 3 technologies: The bus, the SoC core and the debug infrastructure (more than just using the SCR).

- The bus: Advanced Microcontroller Bus Architecture (AMBA) Advanced eXtensible Interface (AXI): The AMBA AXI bus partitions all of the SoC's hardware and software resources by using a set of bits. Ensures no SW resources can be accessed by NW components.

- SoC core: Implement extensions which enable a single physical processor core to safely and efficiently execute code from both NW and SW in time-sliced fashion. Dependent on the NS bit's state at the time of code execution.

- Debug infrastructure Niet belangrijk.

Secure monitor = brug tussen NW en SW.

Arm trustzone boot: Cold reset -> Trusted boot ROM SoC TEE configuration (embedded device config registers blabla vgm) -> Arm Trusted Firmware (ROM of trusted SRAM) -> Trusted OS execution -> NW bootloader execution.
Dus eerste SW helemaal inladen, trusted OS etc, dan pas NW.

We hebben Trusted OS (e.g. OP-TEE) in SW, non-trusted OS (e.g. Linux kernel) in NW.

1.4   Develop Secure Cortex-M Applications with Trustzone

video link

When to use TrustZone:

- If product is connected: e.g. Wi-Fi, Bluetooth, Zigbee, USB, UART ...

- If product is upgradeable: OTA updates, e.g. firmware upgrades, feature upgrades, security upgrades ...

- If product stores valuable information: e.g. Keys, certificates, personal data ... (nvt?)

TrustZone is about isolation: Isolate some application with some assets (e.g. firmware, keys, password ... Could be software or data).

Traditionally, to isolate 2 worlds (SW and NSW) uses 2 CPUs isolated from each other.

TrustZone = 1 CPU with hardware isolation.

In TrustZone enabled device, we have 2 different "views" / states: Non-trusted view and Trusted view. Up to developer to divide what part should be in trusted and non-trusted view. E.g. some secure (trusted) firmware, some non-trusted firmware, some secure data and some normal data, some trusted peripherals and untrusted peripherals, memory ...

Additional states / how Armv8-M architecture facilitates TrustZone:

- Secure and non-secure code run on a single CPU = more efficient for embedded

- In Armv7-M: CPU had Handler mode and Thread mode. In Armv8-M these are mirrored with secure and non-secure states (non-secure handler mode, non-secure thread mode, secure handler mode, secure thread mode).

- Secure state for trusted code: For example added new secure stack pointer (now we have secure and non-secure stack pointer), if we had MPU we now have 1 for the non-trusted view and 1 for trusted view etc.

Priority: Secure vs non-secure view has nothing to do with priority. Secure can interrupt non-secure and vice-versa.

Interrupt handling: Interrupt while executing in SW from NSW: Zero all registers first blabla.

Security defined by address. All addresses are either Secure or non-secure.
Policing managed by Secure Attribution Unit (SAU) = new hardware block inside
of the CPU. Request from CPU goes through SAU, SAU forwards to either secure
MPU or non-secure MPU.
SAU is software-configurable, so developer can define which part of memory is secure
and non-secure.

When trying to access secure address from non-secure state = memory fault.

Memory without TrustZone is divided into multiple regions: System region, de-
vice region, RAM region, peripheral region ....
With TrustZone, each of these regions is also partitioned into secure and non-secure
parts.
This defines access control to all of these regions.

Developing code for secure IoT applications: Project is partitioned into "User project"
and "secure project", 2 different binaries.

Cross-domain function calls: Non-secure side can call some functions on the se-
cure side. Up to developer which functions can be called by NSW.
Then compiler / linker produce some extra code on secure side: "Non-Secure callable"
region.

1.5   Secure Firmware Update over the Air using TrustZone

Samenvatting van https://ieeexplore.ieee.org/document/8959992/references#
references Abstract / Introductie: Doel van paper = gebruik maken van Trust-
Zone TEE om OTA firmware updates (FOTA) secuur te doen. Via digital signature
en dan signature verification in trusted application (SW). Signing mbv RSA

Sectie 2: TEE. Uitleg TrustZone = Low-cost security core for SoC, by providing
2 virtual processors & split resources between SW and NW. Voor extra security
runnen we apart secure OS in de SW, namelijk een TEE.

> As per Global Platform Compliance, "the TEE is a secure area of the
> main processor" and it must "offer isolated safe execution of authorized
> security software".

bv OP-TEE . . .

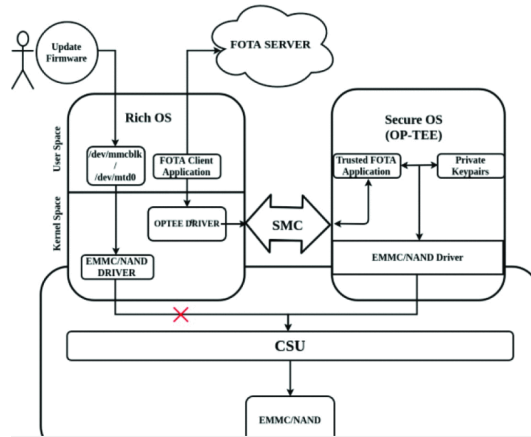Sectie 3: Architectuur voor secure update. Zie **??**, bron = link blabla.

FIGURE 1.1: Architectuur voor de secure updates

Secure server (FOTA server) levert de firmware files.
TEE heeft geen network access dus NW OS doet download.
Nu zijn er 2 applications: "FOTA application" in NW en "trusted application" in SW. Deze communiceren via SMC (Secure Monitor Call).

Dus, "Host application"(FOTA appl.) in NW doet download over secure channel met FOTA server. Gebruikt dan de OP-TEE driver om SMC te doen naar trusted application voor signature verification. Deze RSA crypto shnitzel gebeurt in TEE waar private keys zitten.
Als geverified, schrijft trusted application de firmware file naar flash via flash drivers (NW heeft geen access naar firmware flash region).
De access control policies voor peripherals worden onderhouden door CSU (Central Security Unit). E.g. enkel SW heeft toegang tot de EMMC / NAND waar firmware gestored wordt, CSU blockt calls van NW.

Sectie 4: Implementatie. Deze paper gebruikt ARM Cortex A7, Linux in NW, OP-TEE in SW, U-Boot als bootloader.
Zie andere figuur in de paper voor flow, Trusted Application (TA) wordt pas ingeladen na download van nieuwe firmware. Dus flow is Bootloader start -> Bootloader laadt OP-TEE (SW) -> OP-TEE start Linux (NW) -> FOTA (Host application in NW) wordt geinitialiseerd en checkt of firmware update available is. Als nee, niks (wacht tot een update komt). Als ja -> FOTA application in NW download de firmware van de Secure server -> FOTA application initialiseert de Trusted Application in SW via call (SMC) met UUID voor deze specifieke Trusted Application) -> TA verifieert, schrijft naar EMMC / NAND flash . . . .
Bij inladen van de TA in SW, doen we ook validations vd authenticity etc van de TA eerst. = extra security.

Dit is allemaal zeer interessant en nuttig voor basic implementatie in onze the-

sis, maar is andere richting dan wat wij willen zoeken.

In deze implementatie, wat als een NW application (zeg Bad Application) onze device DoS't door de network stack in de NW hele tijd bezig te houden?

Priority based preemption? -> Application in NW heeft somehow max priority, wat nu? Geen FOTA updates mogelijk?

1.6 Secure FOTA updates for IoT: survey, challenges and discussions

https://www.sciencedirect.com/science/article/pii/S2542660522000142//

1.6.1 Intro en Background

IoT heeft slechte security want security niet zo profitable als eerst zijn.

Veel zero-day attacks.

Daarom is FOTA zo belangrijk, om deze exploits snel te fixen.

In deze paper: Basically beschrijving van huidige landschap (security mechanisms, threats, solutions).

Idk paper praat wel veel uit standpunt van ISP

Background:

New classification voor embedded devices blabla

Secure element is zeer belangrijk om een trusted environment te bekomen (elke device heeft SE waarin crypto shit zit om device te authenticaten etc, malicious devices kunnen uit onze trusted environment gepingeld worden). (Dit is TEE btw, e.g. TrustZone...)

Root-of-trust (verifieer de integriteit en authenticiteit vd software die geload wordt op device) establishen en verder Trust Chain uitbouwen.

Bij TrustZone: Protect keys / certificates, dit is initial layer van RoT. Start boot van IBB en bouw chain verder uit.

Modes of FOTA updates: Pull en Push. Pull = device query't FOTA server periodiek, Push = server-initiated, voor devices die zeer resource-constrained zijn en niet periodiek willen / kunnen checken. Hybrid mode ook mogelijk, partial FOTA updates ook cool.

FOTA update via mobile gateway: Gateway managet meerdere IoT devices. Extra concerns, zie 2.5 evt. Niet zo belangrijk.

1.6.2 FOTA update related threats

Beschrijving van verschillende attack types. 3 categorieen: attacks op IoT devices, op gateways en op suppliers/manufacturers. Vooral geinteresseerd in attacks op IoT devices zelf voor deze.

Since the IoT devices are the weakest node in the update process, the attackers will mainly try to exploit their constraints in order to infiltrate the local network of the user for malicious purposes. In this section, the attacks targeting these devices are highlighted. The "Rollback attack": the hacker re-sends a valid but old firmware version to the devices [2]. "Mismatched firmware": the attacker sends this time a valid firmware but for a different type of IoT device, which will lead to the dysfunction of the device. Thus, the devices become unavailable [18]. Another attack targets the very constrained devices that are most of the time in sleep mode, this attack can be called "Offline update attack". Since some IoT devices are most of the time offline, they may have missed a couple of firmware updates. In this case, the attacker sends a newer version than the one installed in the devices but still not the latest version. This newer version may still have some unpatched vulnerabilities, that can be exploited [18]. "Repeated update requests attack": can be seen as a kind of DoS attack where the malicious peer sends as many as possible new FoTA update requests either with valid or invalid firmware. It leads the IoT device to check the integrity and the authenticity of the firmware each time. This attack provokes the unavailability of the IoT device and extra power consumption, which is problematic for the battery-powered ones. "Device cloning attack": the attacker replicates some IoT devices so that only the cloned one will be updated and not the original devices. In this case, the attacker will simply remove the cloned devices from the network and will try to exploit the unpatched devices. "Non-ephemeral keys attack": in this case, the attacker tries to deduce the asymmetric key pair from all the exchanges that have been done between the IoT device and the other entities, in particular since the IoT device will rarely renegotiate a new pair of keys. The attacker can then forge a signature on a rogue update [18]. "Unchanged default password": is not a particular problem for IoT but for all the devices where the default password was never changed, and where it can be the same for all devices of the same model manufactured by the same manufacturer. Hence, an attacker who possesses a similar device model can suppose that the target has also the same password. Furthermore, a weak password can be easy to guess. In both cases, an attacker may aim to get unauthorized access to the device using the obtained password. "Firmware reverse engineering": is another type of process an attacker can perform, by reverse-engineering the binaries into assembly in order to analyze the functionality and to get access to secret data [2,19].

Deze + de 2 andere categorieen versterken vgm het punt dat deze thesis nuttig is: no matter what, het is mogelijk dat onze device infected raakt. Het is dus belangrijk om, in welke situatie dan ook, de OTA update service available te hebben.

1.6.3   Challenges

- Constraints of IoT devices: Heel zwakke IoT devices hebben mss niet eens capabilities voor authenticity checks (crypto).

- Security & privacy: Integrity en authenticity van de firmware verifieren is belangrijk. End-to-end security mbv chain of trust en safe key-distribution system is de goal

- Interoperability: IoT devices zijn heterogeen, e.g. verschillende HW capabilities, verschillende communication protocols, verschillende architecturen . . . Moeilijk om standardised solution te vinden.

- Verschillende netwerk topologies: P2P, star, mesh . . .

- Establishing trust chain: Zoals eerder gezien, niet altijd mogelijk dat elk element in de chain alles kan authenticaten. Maybe 3rd party nodig die devices monitort . . .

1.6.4   State of the art

Zeeeer interessant, samenvatting en review van een hoop papers, zie hoofdstuk 5. Vooral: [24] TUF, [33] ASSURED (TUF voor o.a. ARM TrustZone-M), [44] (zie 5.2.4) paper die FOTA update over LoraWAN standardiseert

1.7   Plaatsing van ons probleem

We gebruiken ENISA guidelines for securing the IoT.
Deze thesis behandelt 3.3: Nefarious activity/abuse, en meer specifiek Malware insertion.

> Attackers are presented with the opportunity to insert malicious software whose main objective is to provide illicit access or any other functionality that goes against the intended usage of the system. Insecure update mechanisms and poisoned update services are prime examples of such opportunities for malware injection. IoT gateways are especially relevant in this context; these are functional devices that are commonly found in IoT architectures, but can also function as a threats source. IoT gateways usually have a supporting role in the scope of security requirements, they are, however, an avenue to compromise IoT devices for a malicious actor, providing access into trusted networks and a method to acquire data from supported constrained devices.

Ook 3.5: Unintentional damage or loss of information. Meer specifiek Compromise of network

8

Systems that are necessary for the control of supply chain processes and exist in a network could become compromised without the proper QoS or firewall policies. These assets could be weaponized to orchestrate, for example, large scale Denial of Service (DoS) attacks, or to degrade the operation of the supply chain. Those that have access to the Internet are the most vulnerable, although isolated internal networks are also at risk from insider attacks.

en Failure of recovery mechanics

Due to an attack, the system (and the device) is not able to be recovered impacting functionality and security. During the lifecycle of an IoT device, several assets (firmware, configuration, credentials) might need to be updated. Chain of trust must be considered since depending the asset to be updated (impacted), different mechanisms must be used. The recovery plan must define which mechanism and which process must be followed to fix any potential situation that might compromise the service and the security of the device. Depending the level of criticality and the element of the chain that is compromised, the mechanisms must be one or other. This is a critical process in which the security of the device and the system can be compromised.

evt ook undetected software or hardware disruptions of the devices

Systems related in any fashion to the operation of the supply chain should ideally be extensively monitored for an early detection of hardware of software issues. A more proactive approach on detection usually results in a reduced number of disruptions to the supply chain, especially when compared with reactive measures.

Punt van deze sectie is om deze 3.3 te plaatsen in wijdere context van IoT vulnerabilities.

There is a lot to be said and done about security in the IoT sector. This thesis is not trying to tackle all the problems at once . . .
Er is een hele IoT supply chain (zie ENISA guidelines), op elke stap kan iets fout gaan. Enkel security die OTA updates authenticate bv is niet genoeg, het is altijd mogelijk dat iets binnenslipt en bv onze comms DoS't.
Dus de thesis goals / research questions zijn nog steeds relevant IMO.

1.8   Thesis outline

Research question: How can we use a TEE in an IoT device to create a split architecture that guarantees the availability of OTA updates in the case of a possibly compromised Normal World, while minimizing the performance loss?

1.9 NetReach

https://ieeexplore.ieee.org/document/10628625
Idee: RT scheduler toevoegen aan TrustZone en alle critical code in SW = goede availability. Issue: Network stack runt nog in NW, kan nog geDoS't worden.
NetReach oplossing: always available network peripheral in SW + always available network connection naar critical applications in NW.
Basically gewoon: geef NW transmission lage prioriteit.
In normal operation, NW network stack wordt gedeeld tussen NW en SW. Dan ook nog extra backup network connection van SW (aparte MAC en IP) .

Verschil met deze thesis:

- NetReach gebruikt Armv7 A (meer computational power), wij gebruiken Arm Cortex M (meer resource-constrained, M33 specifiek)

- NetReach heeft backup network channel voor SW. Wij willen maar 1 shared channel

- NetReach is split-driver architecture, wij moeten uitzoeken welke manier best is (fair sharing, priority based, meerdere drivers vs 1 driver in SW . . .)

- NetReach DoS protection door priority-based: NW tx lagere prio dan SW. Deze thesis:

1.10 Bronnen

Building a secure system using TrustZone technology: https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://documentation-service.arm.com/static/5f212796500e883ab8e74531&ved=2ahUKEwiMyJLq_4OQAxXLVaQEHdDXNP4QFnoECAsQAQ&usg=AOvVaw1Pe2c9ygxbbg8PjsGQV9XZ

Board: https://www.silabs.com/development-tools/wireless/proprietary/efr32fg23-868-915-mhz-14-dbm-dev-kit?tab=techdocs

Board documentation, Reference manual etc: https://www.silabs.com/support/resources.p-wireless_proprietary_efr32fg23-series-2-socs

Trusted firmware site, zie TF-M: https://www.trustedfirmware.org/

Secure Firmware Update over the Air using TrustZone: https://ieeexplore.ieee.org/document/8959992

ENISA guidelines for securing the IoT: https://www.enisa.europa.eu/sites/default/files/publications/ENISA%20Report%20-%20Guidelines%20for%20Securing%20the%20Internet%20of%20Things.pdf

Basically state of IoT OTA update security anno mei 2022: https://www.sciencedirect.com/science/article/pii/S2542660522000142

NetReach, paper van Tom Van Eyck et al. https://ieeexplore.ieee.org/document/10628625

Chapter 2

The First Chapter

A chapter is a logical unit. It normally starts with an introduction, which you are reading now. The last topic of the chapter holds the conclusion.

2.1 The First Topic of the Chapter

First comes the introduction to this topic.

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2.1.1 An item

Please don't abuse enumerations: short enumerations shouldn't use "`itemize`" or "`enumerate`" environments. So *never write*:

> The Eiffel tower has three floors:
>
> - the first one;
> - the second one;
> - the third one.

But write:

> The Eiffel tower has three floors: the first one, the second one, and the third one.

2.2 A Second Topic

First we start with equation **??** after this paragraph.

$$A = \pi r^2 \tag{2.1}$$

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2.2.1 Another item

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2.3 Conclusion

The final section of the chapter gives an overview of the important results of this chapter. This implies that the introductory chapter and the concluding chapter don't need a conclusion.

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Chapter 3

The Next Chapter

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3.1 The First Topic of this Chapter

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3.1.1 An item

A master's thesis is never an isolated work. This means that your text must contain references. On-line documents[?] as well as books[?] can be referenced.

Usually a text also contains inline formulas ($\sin^2 \eta + \cos^2 \eta = 1$) or formulas as separate equations.

$$\sigma(t) = \frac{1}{\sqrt{2\pi}} \int_0^t e^{-x^2/2} dx \tag{3.1}$$

Figure 3.1: The logo of the Faculty of Engineering Science.

gnats	gram	$13.65
	each	.01
gnu	stuffed	92.50
emu		33.33
armadillo	frozen	8.99

Table 3.1: A table with the wrong layout.

Item		
Animal	Description	Price ($)
Gnat	per gram	13.65
	each	0.01
Gnu	stuffed	92.50
Emu	stuffed	33.33
Armadillo	frozen	8.99

Table 3.2: A table with the correct layout.

3.2 Figures

Figures are used to add illustrations to the text. The Figure **??** shows the KU Leuven logo as an illustration.

3.3 Tables

Tables are used to present data neatly arranged. A table is normally not a spreadsheet! Compare Table **??** en Table **??**: which table do you prefer?

3.4 Lorem Ipsum

This section is added to check headers and footers. So this chapter must at least contain three pages. To make sure that we get the required amount, the lipsum

package isn't used but the text is put directly in the text.

3.4.1 Lorem ipsum dolor sit amet, consectetur adipiscing elit

Sed nec tortor id felis tristique sodales. Nulla nec massa eu dui fermentum tincidunt. Integer ullamcorper ante eget eros posuere faucibus. Nam id ligula ut augue pulvinar vulputate id at purus. Aenean condimentum tortor eu mi placerat eget eleifend massa mollis. Nam est mi, sagittis quis euismod eget, sagittis in nibh. Proin elit turpis, aliquam et imperdiet sed, volutpat eu turpis.

Pellentesque vel enim tellus, vitae egestas turpis. Praesent malesuada elit non nisi sollicitudin non blandit lacus tincidunt. Morbi blandit urna at lectus ornare laoreet. Suspendisse turpis diam, lobortis dictum luctus quis, commodo at lorem. Integer lacinia convallis ultricies. Sed quis augue neque, eu malesuada arcu. Nullam vehicula, purus vitae sagittis pulvinar, erat eros semper massa, eu egestas nibh erat quis magna. Cras pellentesque, nisl eu dapibus volutpat, urna augue ornare quam, quis egestas lectus nulla a lectus.

Vivamus dictum libero in massa cursus sed vulputate eros imperdiet. Donec lacinia, libero ac lobortis egestas, nibh dui ornare arcu, luctus porttitor velit massa sit amet quam. Maecenas scelerisque laoreet diam, vitae congue quam adipiscing vitae. Aliquam cursus nisl a leo convallis eleifend fermentum massa porta. Nunc libero quam, dapibus dapibus molestie sit amet, faucibus vel nunc.

3.4.2 Praesent auctor venenatis posuere

Sed tellus augue, molestie in pulvinar lacinia, dapibus non ipsum. Fusce vitae mi vitae enim ullamcorper hendrerit eu malesuada est. Proin iaculis ante sed nibh tincidunt vel interdum libero posuere. Vivamus accumsan metus quis felis congue suscipit dapibus enim mattis. Fusce mattis tortor eget ipsum interdum sagittis auctor id metus.

Integer diam lacus, pharetra sit amet tempor et, tristique non lorem. Aenean auctor, nisi eu interdum fermentum, lectus massa adipiscing elit, sed facilisis orci odio a lectus. Proin mi nibh, tempus quis porta a, viverra quis enim. In sollicitudin egestas libero, quis viverra velit molestie eget. Nulla rhoncus, dolor a mollis vestibulum, lacus elit semper nisi, nec sollicitudin sem urna eu magna. Nunc sed est urna, euismod congue mi.

3.4.3 Cras vulputate ultricies venenatis

Vivamus eros urna, sodales accumsan semper vel, lobortis sit amet mauris. Etiam condimentum eleifend lorem, ullamcorper ornare lectus aliquet vitae. Praesent massa enim, interdum sit amet semper et, venenatis ut elit. Quisque faucibus, quam ac lacinia imperdiet, nulla neque elementum purus, tempus rutrum justo massa porta sapien. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Sed ultrices interdum mi, et rhoncus sapien rutrum sed.

Duis elit orci, molestie quis sollicitudin sed, convallis non ante. Maecenas tincidunt condimentum justo, et ultricies leo tristique vitae. Vestibulum quis quam non lectus dapibus eleifend a vitae nibh. Nam nibh justo, pharetra quis iaculis consequat, elementum quis justo. Etiam mollis lacinia lacus, nec sollicitudin urna lobortis ac. Nulla facilisi.

Proin placerat risus eleifend erat ultricies placerat. Etiam rutrum magna nec turpis euismod consectetur. Phasellus tortor odio, lacinia imperdiet condimentum sed, faucibus commodo erat. Phasellus sed felis id ante placerat ultrices. Aenean tempor justo in tortor volutpat eu auctor dolor mollis. Aenean sit amet risus urna. Morbi viverra vehicula cursus.

3.4.4 Donec nibh ante, consectetur et posuere id, tempus nec arcu

Curabitur a tellus aliquet ipsum pellentesque scelerisque. Etiam congue, risus et volutpat rutrum, est purus dapibus leo, non cursus metus felis eget ligula. Vivamus facilisis tristique turpis, ut pretium lectus luctus eleifend. Fusce magna sapien, ullamcorper vitae fringilla id, euismod quis ante.

Phasellus volutpat, nunc et pharetra semper, sem justo adipiscing mauris, id blandit magna quam et orci. Vestibulum a erat purus, ut molestie ante. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Proin turpis diam, consequat ut ullamcorper ut, consequat eu orci. Sed metus risus, fringilla nec interdum vel, interdum eu nunc. Suspendisse vel sapien orci.

3.4.5 Morbi et mauris tempus purus ornare vehicula

Mauris sit amet diam quam, eget luctus purus. Sed faucibus, risus semper eleifend iaculis, mi turpis bibendum nisl, quis cursus nibh nisl sit amet ipsum. Vestibulum tempor urna vitae mi auctor malesuada eget non ligula. Nullam convallis, diam vel ultrices auctor, eros eros egestas elit, sed accumsan arcu tortor eget leo. Vestibulum orci purus, porttitor in pharetra eget, tincidunt eget nisl. Nullam sit amet nulla dui, facilisis vestibulum dui.

Donec faucibus facilisis mauris ac cursus. Duis rhoncus quam sed nisi laoreet eu scelerisque massa tincidunt. Vivamus sit amet libero nec arcu imperdiet tempor quis non libero. Sed consequat dignissim justo. Phasellus ullamcorper, velit quis posuere vulputate, felis erat tincidunt mauris, at vestibulum justo lectus et turpis. Maecenas lacinia convallis euismod. Quisque egestas fermentum sapien eu dictum. Sed nec lacus in purus dictum consequat quis vel nisl. Fusce non urna sem. Curabitur eu diam vitae elit accumsan blandit. Nullam fermentum nunc et leo dictum laoreet. Donec semper varius velit vel fringilla. Vivamus eu orci nunc.

3.5 Conclusion

The final section of the chapter gives an overview of the important results of this chapter. This implies that the introductory chapter and the concluding chapter don't need a conclusion.

Nunc sed pede. Praesent vitae lectus. Praesent neque justo, vehicula eget, interdum id, facilisis et, nibh. Phasellus at purus et libero lacinia dictum. Fusce aliquet. Nulla eu ante placerat leo semper dictum. Mauris metus. Curabitur lobortis. Curabitur sollicitudin hendrerit nunc. Donec ultrices lacus id ipsum.

Chapter 4

The Final Chapter

Morbi malesuada hendrerit dui. Nunc mauris leo, dapibus sit amet, vestibulum et, commodo id, est. Pellentesque purus. Pellentesque tristique, nunc ac pulvinar adipiscing, justo eros consequat lectus, sit amet posuere lectus neque vel augue. Cras consectetuer libero ac eros. Ut eget massa. Fusce sit amet enim eleifend sem dictum auctor. In eget risus luctus wisi convallis pulvinar. Vivamus sapien risus, tempor in, viverra in, aliquet pellentesque, eros. Aliquam euismod libero a sem.

4.1 The First Topic of this Chapter

4.1.1 Item 1

Sub-item 1

Nunc velit augue, scelerisque dignissim, lobortis et, aliquam in, risus. In eu eros. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Curabitur vulputate elit viverra augue. Mauris fringilla, tortor sit amet malesuada mollis, sapien mi dapibus odio, ac imperdiet ligula enim eget nisl. Quisque vitae pede a pede aliquet suscipit. Phasellus tellus pede, viverra vestibulum, gravida id, laoreet in, justo. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Integer commodo luctus lectus. Mauris justo. Duis varius eros. Sed quam. Cras lacus eros, rutrum eget, varius quis, convallis iaculis, velit. Mauris imperdiet, metus at tristique venenatis, purus neque pellentesque mauris, a ultrices elit lacus nec tortor. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Praesent malesuada. Nam lacus lectus, auctor sit amet, malesuada vel, elementum eget, metus. Duis neque pede, facilisis eget, egestas elementum, nonummy id, neque.

Sub-item 2

Proin non sem. Donec nec erat. Proin libero. Aliquam viverra arcu. Donec vitae purus. Donec felis mi, semper id, scelerisque porta, sollicitudin sed, turpis. Nulla in urna. Integer varius wisi non elit. Etiam nec sem. Mauris consequat, risus nec

congue condimentum, ligula ligula suscipit urna, vitae porta odio erat quis sapien. Proin luctus leo id erat. Etiam massa metus, accumsan pellentesque, sagittis sit amet, venenatis nec, mauris. Praesent urna eros, ornare nec, vulputate eget, cursus sed, justo. Phasellus nec lorem. Nullam ligula ligula, mollis sit amet, faucibus vel, eleifend ac, dui. Aliquam erat volutpat.

4.1.2   Item 2

Fusce vehicula, tortor et gravida porttitor, metus nibh congue lorem, ut tempus purus mauris a pede. Integer tincidunt orci sit amet turpis. Aenean a metus. Aliquam vestibulum lobortis felis. Donec gravida. Sed sed urna. Mauris et orci. Integer ultrices feugiat ligula. Sed dignissim nibh a massa. Donec orci dui, tempor sed, tincidunt nonummy, viverra sit amet, turpis. Quisque lobortis. Proin venenatis tortor nec wisi. Vestibulum placerat. In hac habitasse platea dictumst. Aliquam porta mi quis risus. Donec sagittis luctus diam. Nam ipsum elit, imperdiet vitae, faucibus nec, fringilla eget, leo. Etiam quis dolor in sapien porttitor imperdiet.

4.2   The Second Topic

Cras pretium. Nulla malesuada ipsum ut libero. Suspendisse gravida hendrerit tellus. Maecenas quis lacus. Morbi fringilla. Vestibulum odio turpis, tempor vitae, scelerisque a, dictum non, massa. Praesent erat felis, porta sit amet, condimentum sit amet, placerat et, turpis. Praesent placerat lacus a enim. Vestibulum non eros. Ut congue. Donec tristique varius tortor. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Nam dictum dictum urna.

Phasellus vestibulum orci vel mauris. Fusce quam leo, adipiscing ac, pulvinar eget, molestie sit amet, erat. Sed diam. Suspendisse eros leo, tempus eget, dapibus sit amet, tempus eu, arcu. Vestibulum wisi metus, dapibus vel, luctus sit amet, condimentum quis, leo. Suspendisse molestie. Duis in ante. Ut sodales sem sit amet mauris. Suspendisse ornare pretium orci. Fusce tristique enim eget mi. Vestibulum eros elit, gravida ac, pharetra sed, lobortis in, massa. Proin at dolor. Duis accumsan accumsan pede. Nullam blandit elit in magna lacinia hendrerit. Ut nonummy luctus eros. Fusce eget tortor.

Ut sit amet magna. Cras a ligula eu urna dignissim viverra. Nullam tempor leo porta ipsum. Praesent purus. Nullam consequat. Mauris dictum sagittis dui. Vestibulum sollicitudin consectetuer wisi. In sit amet diam. Nullam malesuada pharetra risus. Proin lacus arcu, eleifend sed, vehicula at, congue sit amet, sem. Sed sagittis pede a nisl. Sed tincidunt odio a pede. Sed dui. Nam eu enim. Aliquam sagittis lacus eget libero. Pellentesque diam sem, sagittis molestie, tristique et, fermentum ornare, nibh. Nulla et tellus non felis imperdiet mattis. Aliquam erat volutpat.

4.3 Conclusion

Vestibulum sodales ipsum id augue. Integer ipsum pede, convallis sit amet, tristique vitae, tempor ut, nunc. Nam non ligula non lorem convallis hendrerit. Maecenas hendrerit. Sed magna odio, aliquam imperdiet, porta ac, aliquet eget, mi. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Vestibulum nisl sem, dignissim vel, euismod quis, egestas ut, orci. Nunc vitae risus vel metus euismod laoreet. Cras sit amet neque a turpis lobortis auctor. Sed aliquam sem ac elit. Cras velit lectus, facilisis id, dictum sed, porta rutrum, nisl. Nam hendrerit ipsum sed augue. Nullam scelerisque hendrerit wisi. Vivamus egestas arcu sed purus. Ut ornare lectus sed eros. Suspendisse potenti. Mauris sollicitudin pede vel velit. In hac habitasse platea dictumst.

Suspendisse erat mauris, nonummy eget, pretium eget, consequat vel, justo. Pellentesque consectetuer erat sed lacus. Nullam egestas nulla ac dui. Donec cursus rhoncus ipsum. Nunc et sem eu magna egestas malesuada. Vivamus dictum massa at dolor. Morbi est nulla, faucibus ac, posuere in, interdum ut, sapien. Proin consectetuer pretium urna. Donec sit amet nibh nec purus dignissim mattis. Phasellus vehicula elit at lacus. Nulla facilisi. Cras ut arcu. Sed consectetuer. Integer tristique elit quis felis consectetuer eleifend. Cras et lectus.

Ut congue malesuada justo. Curabitur congue, felis at hendrerit faucibus, mauris lacus porttitor pede, nec aliquam turpis diam feugiat arcu. Nullam rhoncus ipsum at risus. Vestibulum a dolor sed dolor fermentum vulputate. Sed nec ipsum dapibus urna bibendum lobortis. Vestibulum elit. Nam ligula arcu, volutpat eget, lacinia eu, lobortis ac, urna. Nam mollis ultrices nulla. Cras vulputate. Suspendisse at risus at metus pulvinar malesuada. Nullam lacus. Aliquam tempus magna. Aliquam ut purus. Proin tellus.

Chapter 5

Conclusion

The final chapter contains the overall conclusion. It also contains suggestions for future work and industrial applications.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

Quisque ullamcorper placerat ipsum. Cras nibh. Morbi vel justo vitae lacus tincidunt ultrices. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. In

hac habitasse platea dictumst. Integer tempus convallis augue. Etiam facilisis. Nunc elementum fermentum wisi. Aenean placerat. Ut imperdiet, enim sed gravida sollicitudin, felis odio placerat quam, ac pulvinar elit purus eget enim. Nunc vitae tortor. Proin tempus nibh sit amet nisl. Vivamus quis tortor vitae risus porta vehicula.

Fusce mauris. Vestibulum luctus nibh at lectus. Sed bibendum, nulla a faucibus semper, leo velit ultricies tellus, ac venenatis arcu wisi vel nisl. Vestibulum diam. Aliquam pellentesque, augue quis sagittis posuere, turpis lacus congue quam, in hendrerit risus eros eget felis. Maecenas eget erat in sapien mattis porttitor. Vestibulum porttitor. Nulla facilisi. Sed a turpis eu lacus commodo facilisis. Morbi fringilla, wisi in dignissim interdum, justo lectus sagittis dui, et vehicula libero dui cursus dui. Mauris tempor ligula sed lacus. Duis cursus enim ut augue. Cras ac magna. Cras nulla. Nulla egestas. Curabitur a leo. Quisque egestas wisi eget nunc. Nam feugiat lacus vel est. Curabitur consectetuer.

Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean faucibus pede eu ante. Praesent enim elit, rutrum at, molestie non, nonummy vel, nisl. Ut lectus eros, malesuada sit amet, fermentum eu, sodales cursus, magna. Donec eu purus. Quisque vehicula, urna sed ultricies auctor, pede lorem egestas dui, et convallis elit erat sed nulla. Donec luctus. Curabitur et nunc. Aliquam dolor odio, commodo pretium, ultricies non, pharetra in, velit. Integer arcu est, nonummy in, fermentum faucibus, egestas vel, odio.

Sed commodo posuere pede. Mauris ut est. Ut quis purus. Sed ac odio. Sed vehicula hendrerit sem. Duis non odio. Morbi ut dui. Sed accumsan risus eget odio. In hac habitasse platea dictumst. Pellentesque non elit. Fusce sed justo eu urna porta tincidunt. Mauris felis odio, sollicitudin sed, volutpat a, ornare ac, erat. Morbi quis dolor. Donec pellentesque, erat ac sagittis semper, nunc dui lobortis purus, quis congue purus metus ultricies tellus. Proin et quam. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Praesent sapien turpis, fermentum vel, eleifend faucibus, vehicula eu, lacus.

Appendices

Appendix A

The First Appendix

Appendices hold useful data which is not essential to understand the work done in the master's thesis. An example is a (program) source. An appendix can also have sections as well as figures and references[?].

A.1 More Lorem

Quisque facilisis auctor sapien. Pellentesque gravida hendrerit lectus. Mauris rutrum sodales sapien. Fusce hendrerit sem vel lorem. Integer pellentesque massa vel augue. Integer elit tortor, feugiat quis, sagittis et, ornare non, lacus. Vestibulum posuere pellentesque eros. Quisque venenatis ipsum dictum nulla. Aliquam quis quam non metus eleifend interdum. Nam eget sapien ac mauris malesuada adipiscing. Etiam eleifend neque sed quam. Nulla facilisi. Proin a ligula. Sed id dui eu nibh egestas tincidunt. Suspendisse arcu.

A.1.1 Lorem 15–17

Nulla in ipsum. Praesent eros nulla, congue vitae, euismod ut, commodo a, wisi. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Aenean nonummy magna non leo. Sed felis erat, ullamcorper in, dictum non, ultricies ut, lectus. Proin vel arcu a odio lobortis euismod. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Proin ut est. Aliquam odio. Pellentesque massa turpis, cursus eu, euismod nec, tempor congue, nulla. Duis viverra gravida mauris. Cras tincidunt. Curabitur eros ligula, varius ut, pulvinar in, cursus faucibus, augue.

Nulla mattis luctus nulla. Duis commodo velit at leo. Aliquam vulputate magna et leo. Nam vestibulum ullamcorper leo. Vestibulum condimentum rutrum mauris. Donec id mauris. Morbi molestie justo et pede. Vivamus eget turpis sed nisl cursus tempor. Curabitur mollis sapien condimentum nunc. In wisi nisl, malesuada at, dignissim sit amet, lobortis in, odio. Aenean consequat arcu a ante. Pellentesque porta elit sit amet orci. Etiam at turpis nec elit ultricies imperdiet. Nulla facilisi.

In hac habitasse platea dictumst. Suspendisse viverra aliquam risus. Nullam pede justo, molestie nonummy, scelerisque eu, facilisis vel, arcu.

Curabitur tellus magna, porttitor a, commodo a, commodo in, tortor. Donec interdum. Praesent scelerisque. Maecenas posuere sodales odio. Vivamus metus lacus, varius quis, imperdiet quis, rhoncus a, turpis. Etiam ligula arcu, elementum a, venenatis quis, sollicitudin sed, metus. Donec nunc pede, tincidunt in, venenatis vitae, faucibus vel, nibh. Pellentesque wisi. Nullam malesuada. Morbi ut tellus ut pede tincidunt porta. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam congue neque id dolor.

A.1.2 Lorem 18–19

Donec et nisl at wisi luctus bibendum. Nam interdum tellus ac libero. Sed sem justo, laoreet vitae, fringilla at, adipiscing ut, nibh. Maecenas non sem quis tortor eleifend fermentum. Etiam id tortor ac mauris porta vulputate. Integer porta neque vitae massa. Maecenas tempus libero a libero posuere dictum. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Aenean quis mauris sed elit commodo placerat. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Vivamus rhoncus tincidunt libero. Etiam elementum pretium justo. Vivamus est. Morbi a tellus eget pede tristique commodo. Nulla nisl. Vestibulum sed nisl eu sapien cursus rutrum.

Nulla non mauris vitae wisi posuere convallis. Sed eu nulla nec eros scelerisque pharetra. Nullam varius. Etiam dignissim elementum metus. Vestibulum faucibus, metus sit amet mattis rhoncus, sapien dui laoreet odio, nec ultricies nibh augue a enim. Fusce in ligula. Quisque at magna et nulla commodo consequat. Proin accumsan imperdiet sem. Nunc porta. Donec feugiat mi at justo. Phasellus facilisis ipsum quis ante. In ac elit eget ipsum pharetra faucibus. Maecenas viverra nulla in massa.

A.2 Lorem 51

Maecenas dui. Aliquam volutpat auctor lorem. Cras placerat est vitae lectus. Curabitur massa lectus, rutrum euismod, dignissim ut, dapibus a, odio. Ut eros erat, vulputate ut, interdum non, porta eu, erat. Cras fermentum, felis in porta congue, velit leo facilisis odio, vitae consectetuer lorem quam vitae orci. Sed ultrices, pede eu placerat auctor, ante ligula rutrum tellus, vel posuere nibh lacus nec nibh. Maecenas laoreet dolor at enim. Donec molestie dolor nec metus. Vestibulum libero. Sed quis erat. Sed tristique. Duis pede leo, fermentum quis, consectetuer eget, vulputate sit amet, erat.

Appendix B

The Last Appendix

Appendices are numbered with letters, but the sections and subsections use arabic numerals, as can be seen below.

B.1   Lorem 20-24

Nulla ac nisl. Nullam urna nulla, ullamcorper in, interdum sit amet, gravida ut, risus. Aenean ac enim. In luctus. Phasellus eu quam vitae turpis viverra pellentesque. Duis feugiat felis ut enim. Phasellus pharetra, sem id porttitor sodales, magna nunc aliquet nibh, nec blandit nisl mauris at pede. Suspendisse risus risus, lobortis eget, semper at, imperdiet sit amet, quam. Quisque scelerisque dapibus nibh. Nam enim. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Nunc ut metus. Ut metus justo, auctor at, ultrices eu, sagittis ut, purus. Aliquam aliquam.

Etiam pede massa, dapibus vitae, rhoncus in, placerat posuere, odio. Vestibulum luctus commodo lacus. Morbi lacus dui, tempor sed, euismod eget, condimentum at, tortor. Phasellus aliquet odio ac lacus tempor faucibus. Praesent sed sem. Praesent iaculis. Cras rhoncus tellus sed justo ullamcorper sagittis. Donec quis orci. Sed ut tortor quis tellus euismod tincidunt. Suspendisse congue nisl eu elit. Aliquam tortor diam, tempus id, tristique eget, sodales vel, nulla. Praesent tellus mi, condimentum sed, viverra at, consectetuer quis, lectus. In auctor vehicula orci. Sed pede sapien, euismod in, suscipit in, pharetra placerat, metus. Vivamus commodo dui non odio. Donec et felis.

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B.2 Lorem 25-27

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