



# UNIVERSITÀ DI TRENTO

Dipartimento di Ingegneria e Scienza dell'Informazione  
Department of Information Engineering and Computer Science

Bachelor's Degree in  
Computer Science

FINAL DISSERTATION

## HTTP STL - SECURITY TESTING LANGUAGE AND IMPLEMENTATION

*Sottotitolo (alcune volte lungo - opzionale)*

Supervisor  
Silvio Ranise

Student  
Matteo Bitussi

Co-Supervisors  
Andrea Bisegna  
Roberto Carbone

Academic year 2021/2022

# Ringraziamenti

*...thanks to... TODO (in italiano)*

# Contents

<b>Abstract</b>	<b>3</b>
<b>1 Introduction</b>	<b>4</b>
<b>2 Background</b>	<b>4</b>
2.1 Burp Suite . . . . .	4
2.2 JSON . . . . .	5
2.3 Regex . . . . .	5
2.4 HTTP protocol . . . . .	5
2.5 IdM protocols: SAML and OAuth . . . . .	5
2.5.1 OAuth . . . . .	5
2.5.2 SAML . . . . .	5
<b>3 Design of the testing language</b>	<b>5</b>
3.1 Test example: PKCE Downgrade . . . . .	6
3.2 Language structure . . . . .	6
3.2.1 Test suite . . . . .	6
3.2.2 Test . . . . .	6
3.2.3 Operation . . . . .	8
3.2.4 Message Operation . . . . .	9
3.2.5 Message type definition . . . . .	10
3.3 The oracle . . . . .	11
3.4 Sessions . . . . .	11
<b>4 Implementation</b>	<b>12</b>
4.1 The tool . . . . .	12
4.1.1 Interface of the tool . . . . .	12
4.1.2 Test execution . . . . .	13
4.1.3 Decoding & encoding of parameters . . . . .	14
4.1.4 SAML certificate managing . . . . .	14
4.1.5 Oracle . . . . .	14
4.1.6 Session managing . . . . .	14
<b>5 Uses cases</b>	<b>14</b>
5.1 SAML Use-Case . . . . .	14
5.2 OAuth & OIDC Use-Case . . . . .	14
<b>6 Related work</b>	<b>14</b>
6.1 Micro ID Gym . . . . .	15
6.2 SSO Testing language and Plugin . . . . .	15
<b>7 Conclusions, Limitations and Future Works</b>	<b>15</b>
<b>Bibliografia</b>	<b>16</b>

A Language compartison 1	18
B PKCE test Example complete	19

# Abstract

This thesis covers the work started in my internship at FBK in the context of Single-Sign-On (SSO) protocols testing. SSO protocols are becoming more and more popular these days, and are being used in very sensitive applications such as SPID or CIE. Seeing the vast number of different implementations that are being used from whatever type of service, there is the need to test them in order to ensure that (at least) the known most common vulnerabilities are avoided.

To avoid having to manually test each implementation, an automatic tool is necessary. Moreover, a standard language to define these test suites has to be defined. This is what will be shown in this paper.

# 1 Introduction

In the last years, we are seeing a constant transition from physical to virtual, this is the case of bank transactions, government documents, health care data, and almost anything that can be virtualized. This is a great step forward, the storage is optimized and more easily accessible, facilitating the cataloging of the document. But there are also some big concerns about security of that data, as it is virtual, the access to it is regulated by some authentication protocols instead of a physical identification of the subject accessing the physical documents. This means that we have to be sure that the person accessing the data is the one that is claiming to be. The three basic principles over which data security is based are confidentiality, integrity and availability of data, this is called the CIA triad [6]. If those requirements are not met, sensitive data could be inaccessible or even at risk of access from unauthorized parties, as a result, critical services for health care could be inaccessible, this is what happened for example in Lazio [13] [7], Italy on August 2021, where because of a RansomWare infecting the internal computer network of the region, and keeping it down for multiple days, the covid vaccines and other health-care services could not be booked. Moreover, a lot of data in the systems has been encrypted, and so, denied of any access. It has to be said that preventing RansomWares infections is not the scope of this thesis, but this is a good example of what the consequences of exploiting a vulnerability could be. To ensure the this requirements are satisfied, there is a need to test all the implementations of the protocols and system that are liable of the security of the data. Due to the fast-evolving nature of protocols, new vulnerabilities will eventually be found, and so, new tests will have to be defined or old tests would have to be edited. This is a lot of work to be done by a security tester, and the problem is that not always the person testing the implementation is qualified to do it. The result is that some vulnerabilities could remain undiscovered, representing a weakness in the system.

An automated tool to test implementations of security protocols using a well-known list of vulnerabilities to be tested is needed, this is what the work described in this thesis is all about. Some tools to test specific protocols and vulnerabilities already exist [4][10], but they are usually very specific and hardcoded in a way that the tests could not be easily edited. With this work, I wanted to create a tool that could be used to test any type of protocol that ran over HTTP, and that could define the tests in a very abstract way, allowing edit and additions. In order to do this, a new language will be used to define the tests, and a software will be implemented to execute those tests. The test result will be evaluated by an oracle, that is composed by a series of components that are responsible for telling if the test is passed or not.

In this thesis the design and implementation of this new tool will be discussed.

## 2 Background

In this chapter the subjects needed to comprehend the rest of the thesis will be discussed. The most common subjects will be ignored, giving a focus on the more specific and less common ones.

### 2.1 Burp Suite

Burp is one of the most used application security testing software for web security testing. It works by the use of a proxy server over which a browser redirect the traffic to. The proxy does like a Man In The Middle attack, taking the input traffick from the browser and replying the messages to the target

service, giving also transparency over the TSL or SSL encryption. Burp has access to the proxy, it can sniff HTTP packets and can edit them before they are forwarded to the browser or the target service. Burp also gives the possibility of creating custom plugins giving to the developers access to the java API. This is exactly how the tool will be implemented, using burp as a base over which develop the software that will be executing the tests. The plugin (from now on tool) will be able to intercept, read and edit messages that pass through the burp's proxy by the use of Burp's API.

## **2.2 JSON**

## **2.3 Regex**

## **2.4 HTTP protocol**

## **2.5 IdM protocols: SAML and OAuth**

The so-called IdM protocols are protocols that deal with identity management. For the scope of this thesis, SAML and OAuth 2.0 (from now on OAuth) will be discussed, as they are used in examples and in the related works.

Both SAML and OAuth are Single Sign-On (SSO) protocols, that "is an authentication scheme that allows a user to log in with a single ID and password to any of several related, yet independent, software systems" - [15]. The difference between SAML (Security Assertion Markup Language) and OAuth is how they work, but their objective is the same, to certificate the identity of a given person.

### **2.5.1 OAuth**

As stated in [11], The OAuth authorization framework enables a third-party application to obtain limited access to an HTTP service, either on behalf of a resource owner by orchestrating an approval interaction between the resource owner and the HTTP service, or by allowing the third-party application to obtain access on its own behalf. A series of messages has to be exchanged between the two parties in order to authenticate a resource owner that wants to access some reserved data in a service.

### **2.5.2 SAML**

As stated in [5], The Security Assertion Markup Language (SAML) 2.0 is an XML-based framework that allows identity and security information to be shared across security domains. The Assertion, an XML security token, is a fundamental construct of SAML that is often adopted for use in other protocols and specifications. An Assertion is generally issued by an Identity Provider and consumed by a Service Provider that relies on its content to identify the Assertion's subject for security-related purposes.

# **3 Design of the testing language**

In this chapter it will be introduced how the tool and the testing language had been designed. The idea was to think of a language that could implement all the possible actions which a security tester would be wanting to do on the messages. One of the objective was to think of a language that could define tests that could then be tested over multiple webservices. For example, a series of tests to verify the well-known vulnerabilities of a specific protocol could be defined and then used on any type of website. I had to decide how to write and define the tests, I thought I could define a proper language with a dedicated parser, but it was not worth the effort, as there were already some well-tested alternatives available. one of them is JSON, which has been used as a base over which write the tests. JSON is a convenient way of defining gerarchical sturctures like tests are. The idea behind this language is that a specific message can be intercepted and checked or edited in some way. The gerarchical structure and the details of the language will be discussed in this chapter.

### 3.1 Test example: PKCE Downgrade

I want to introduce the language with an example. Due to its complexity, having a real example before the explanation of all its components could be helpful to understand their use. To understand this test, a brief introduction of PKCE has to be done, as said in [3]: The Proof Key for Code Exchange (PKCE, pronounced pixie) extension describes a technique for public clients to mitigate the threat of having the authorization code intercepted. The technique involves the client first creating a secret, and then using that secret again when exchanging the authorization code for an access token. This way if the code is intercepted, it will not be useful since the token request relies on the initial secret. The PKCE Downgrade test has as objective to test an OAuth vulnerability where removing the parameter "code\_challenge" from the url of an authorization request message will be downgrading the authentication proces in a way that PKCE will not be used if the service is vulnerable [14]. To test this, we have to intercept the authorization request message, remove the parameter "code\_challenge" from it, and then forward it. The complete test can be found in attachment B

### 3.2 Language structure

Each object of the language is a JSON object which can contain different possible tags based on its type.

#### 3.2.1 Test suite

The test suite is the main Object which contains all the other one, it has these tags:

- name, the name of the test suite
- description, the description of the test suite
- tests, which is a list containing the tests to be executed

Referring to the test example above, the definition of the test suite for it is:

```
1 {  
2   "test suite": {  
3     "name": "OAuth active tests",  
4     "description": "A test suite containing a OAuth test"  
5   },  
6   "tests": [  
7     {  
8       // A test  
9     }  
10  ]  
11 }
```

As we can see, the Test Suite Object is a JSON object having the tag "test suite", with name and description, and a tag "tests" which will contain a list of Test Objects.

#### 3.2.2 Test

Following the gerarchical order, the Test object is the one that actually defines a test. As said earlier, a test is contained in a Test Suite, and has various tags to be defined:

- name
- description
- type, it can be "active" or "passive"
- sessions, which is a list of the sessions which are needed in this test
- result, (only for actives) it defines the conditions over which the test is considered passed or not.
- operations, a list of Operation objects which will be executed.



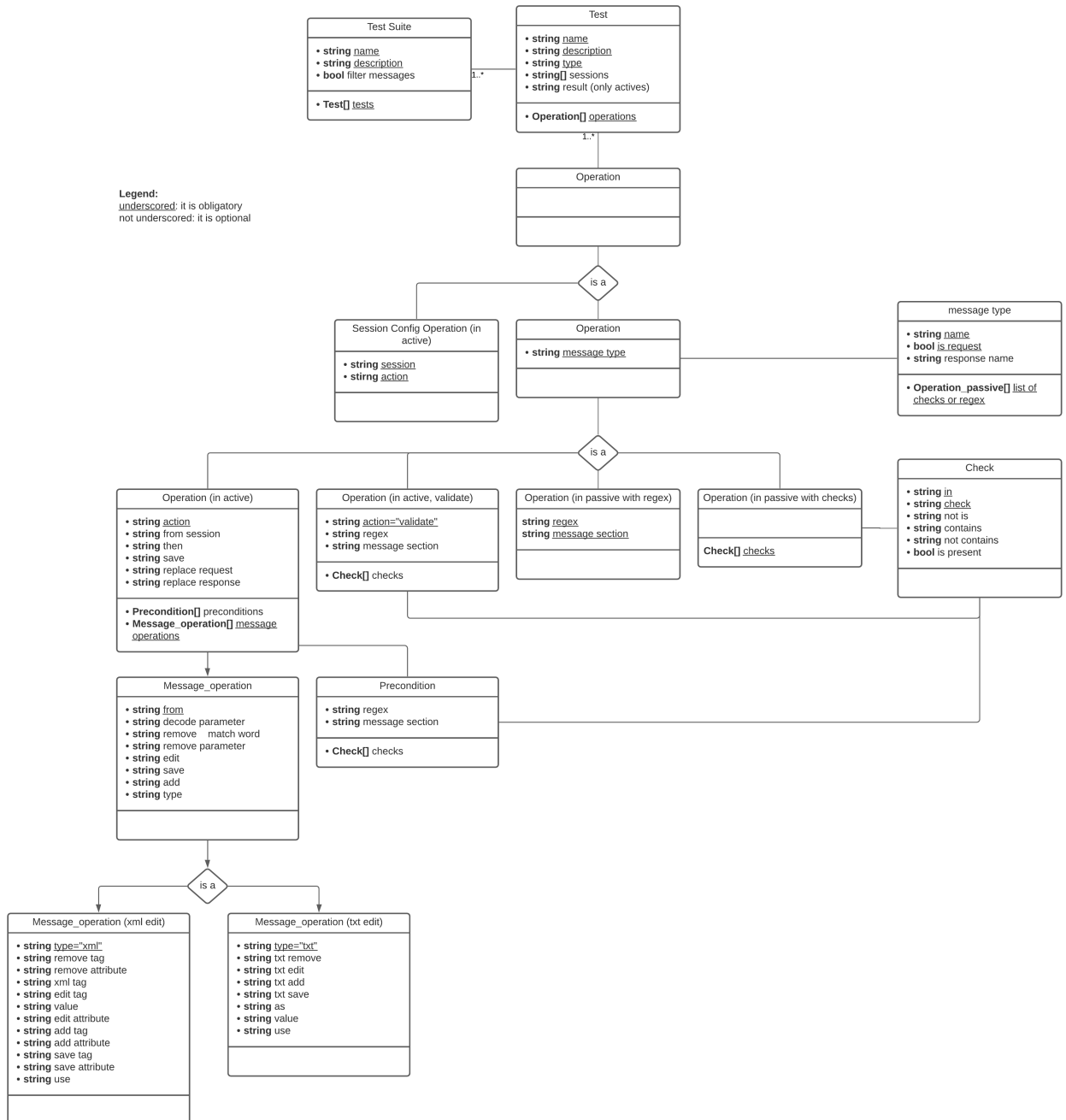


Figure 3.1: language structure

A test can be defined either as active or passive depending on the type of actions it has to do on the intercepted messages. If a test doesn't need to manipulate the flow or the content of the messages is considered passive, otherwise it is considered active. The list of Operation Objects contained in a Test is executed iteratively one after the other. Only after the actual Operation has finished the execution the next is started.

Following the PKCE example above, we define an active Test:

```
1 {
2   "test": {
3     "name": "PKCE Downgrade",
4     "description": "Tries to remove code_challenge parameter",
5     "type": "active",
6     "sessions": [
7       "s1"
8     ],
9     "operations": [
10      // list of Operation Objects
11    ],
12    "result": "incorrect flow s1"
13  }
14 }
```

We define the test, specifying its type, which is active, as it has to edit a message removing a parameter from the url, we define a session to be used (more on that later in this chapter) and we add a list of Operation to be executed. The result of the test is also specified, this will also be discussed later in the chapter.

### 3.2.3 Operation

The Operation object is the component that defines what a test actually does. As shown in the language structure image 3.1, an operation could be either a standard operation or a session config operation, the latter is used to manage the sessions for the active tests (i.e. start, stop, pause them). Depending on the type of test which an Operation is defined into, the standard Operation becomes active or passive. In both cases, an operation has to contain the **message type** which defines the type of message to be intercepted in that particular operation (more info in the dedicated paragraph). A **passive** operation has as objective to verify the presence (or absence) of some text or parameters in the intercepted message, to do this, it should contain one of the following options:

- A list of Check objects, which are then executed to check the presence (or absence) of some text or parameter
- A regex inspection, which executes an inspection considering the intercepted message as plain text and executing a regex over it, if the regex has a match, the operation is considered passed, otherwise failed. Note that when a regex is used, it has to be specified also the message section over which to execute it (body, header, url)

If the Test where the operations are defined is an **active** test, also if the intercepted messages need to be manipulated in some way, an active Operation has to be defined. It is composed by:

- action, the action it has to do (intercept, validate)
- from session, from which session to expect the message to be intercepted
- then, the action to do after the receiving and manipulation of the message (forward or drop)
- replace request (or response), specify a previously saved message in order to replace it to the intercepted one
- preconditions, a list of Precondition objects
- message operations, a list of Message Operation objects, which will do the actual manipulation of the intercepted message

If the action is set to "**validate**" the operation becomes like a passive operation, because its objective is just to verify that some messages are as wanted. It will contain or a regex or a list of checks to be done. The Validate Operation is part of the Oracle, that is the component that decides whether the tests should be considered passed or not, more details on Oracle section.

In the PKCE example above, we define an Operation Object for an active test. This Operation has to intercept the "authorization request" message from session "s1", it has to check some Preconditions over it and then do some Message Operations. At the end the message is forwarded. More details on preconditions and Message operations in the next sections.

```
1 {
2   "action": "intercept",
3   "from session": "s1",
4   "then": "forward",
5   "message type": "authorization request",
6   "preconditions": [
7     // Precondition list
8   ],
9   "message operations": [
10    // Message Operation list
11  ]
12 }
```

### 3.2.4 Message Operation

The message operation is the Object that actually does the manipulations on the intercepted messages. It is composed by these tags:

- from, the message section to work on
- decode parameter (optional) it indicates which parameter or string to be decoded before processed
- encodings (optional) the list of encodings to be applied to the parameter or text to be decoded. The supported encodings are base64, deflate, url
- remove match word (optional), remove text from the specified section in the matched message, it uses a regex
- edit, edit the matched text
- save, (optional) used to save an entire message in a variable in a way it can be used in future operations
- add, (optional) add some text after the matched text
- type (optional) specify the type of edit you want to do over a decoded parameter

In a message operation there is the possibility to specify a parameter or some text to be decoded before manipulation, to do that, specify with "decode parameter" the parameter to be decoded and with "encodings" the encodings necessary to decode the parameter. The parameter (or text) decoded, at the end of the Message operation will be encoded again automatically. The decoded parameter can be manipulated by means of the "**type**" tag, there is the possibility to interpret the decoded parameter as plain text, and to edit it using some actions:

- txt remove
- txt edit
- txt add
- txt save

All the previous tags accept a regex, and whatever that regex matches will be edited or added or saved based on the specified tag.

Another possibility is to interpret the decoded text as xml, assigning the type tag "xml". This way we have various possible operations to be done on the xml:

- remove tag
- remove attribute
- edit tag
- edit attribute
- add tag
- add attribute
- save tag
- save attribute

In the PKCE example above, we have just a simple Message Operation which has to remove the parameter "code\_challenge" from the url of the message, so the resulting Message Operation will be:

```
1 {  
2   "from": "url",  
3   "remove parameter": "code_challenge"  
4 }
```

### 3.2.5 Message type definition

The message type definition is needed in order to define some types of message that will be later used in the language to intercept them. The message type definition is not actually part of the language, but it is stored in a file in the burp folder. Anyway, the definition of the type of messages uses the same Objects as the language. A message type object is defined using these tags:

- name, the name that will be used in the language to refer to this message type
- is request, if set to true if the searched message is a request, false otherwise
- response name, the name that will be used in the language to refer to the response of the searched message
- checks, a list of Check objects used to identify the message. If evaluated to true, the message is considered found

This is an example that defines the SAML request and the SAML response messages

```
1 {  
2   "message_types": [  
3     {  
4       "name": "saml request",  
5       "is request": true,  
6       "checks": [  
7         {  
8           "in": "url",  
9           "check param": "SAMLRequest",  
10          "is present": true  
11        }  
12      ]  
13    },  
14    {  
15      "name": "saml response",
```

```

16         "is request": true,
17         "checks": [
18             {
19                 "in": "body",
20                 "check param": "SAMLResponse",
21                 "is present": true
22             }
23         ]
24     }
25 ]
26 }

```

The SAML request message has in its url the parameter "SAMLRequest", the SAML response message instead, has the "SAMLResponse" parameter in the body. Then, if a saml request has to be intercepted in a test, it has to be defined in the message types, and then used in the Operation. As a result, if "saml request" is used in an Operation, the message having the parameter "SAMLRequest" in his url will be intercepted and processed by the Operation.

### 3.3 The oracle

The ensemble of all parts of the language that decide the result of the tests is called Oracle, the oracle decides whether a test should be considered passed or failed (or not applicable). I decided to build the oracle in a way that can be almost fully customized by the user. The oracle is based on three main components:

- Evaluation of the complete (or incomplete) execution of the session track
- Evaluation of the Precondition objects
- Evaluation of the Validate objects

If all the above conditions are met, the test is considered passed, otherwise it is considered failed. The oracle can be built for example by using Validate objects to verify that some intercepted messages satisfy some conditions like having a particular parameter or string in them.

From the PKCE example above, both the result of the test and the precondition as been used:

```

1 "preconditions": [
2     {
3         "in": "url",
4         "check param": "code_challenge",
5         "is present": true
6     }
7 ],

```

With this precondition, the test has to be considered "not applicable" if the parameter code\_challenge is not found in the authorization request message. This means that is not possible to execute the given test over the actual intercepted message if the preconditions are not satisfied. The result tag of the Test in the PKCE example is set to:

```

1 "result": "incorrect flow s1"

```

this means that the oracle will evaluate the test as passed if and only if the execution of the session track of the session s1 will be incorrect, this means that if the browser will encounter some type of page which was not meant to encounter, the test will be considered passed. With "was not meant to encounter" I mean that the actions in the session track cannot be done, because the objects that should be pressed in the page are not present, this happens for example if an error page is displayed, which tells us the service is not vulnerable to the Test, so the test is passed.

### 3.4 Sessions

A session is a browser executing a session track, which is a list of user actions that the browser will execute automatically during execution of the Tests. There is the possibility of defining and using

more than one session, in a way that (i.e.) reply tests can be executed. As said in the previous sections, a "from session" tag can be specified in the Operation, this will tell in which of the available session search the desired message. To define the session track I have used and extended the idea used in [12][10][8], adding some options like "wait" and "clear cookies" functionalities. The syntax of the session track is based on the plain text export of Katalon Recorder[2]. An example of a session track that does the login at unitn.it:

```
1  open | https://www.google.com/ |
2  click | id=L2AGLb |
3  click | link=Accedi |
4  click | id=identifierId |
5  type | id=identifierId | matteo.bitussi@studenti.unitn.it
6  click | id=identifierNext |
7  click | id=clid |
8  type | id=clid | matteo.bitussi@unitn.it
9  click | id=inputPassword |
10 type | id=inputPassword | password
11 click | id=btnAccedi |
12 click | link=Gmail |
```

This session track will do the login on the Unitn website using some credentials and password. The supported actions are:

- open | url |, to open an url
- click | id=, link=, xpath= |, to click on a http object with the given id, link or xpath
- type | id= | text, to write on a given http element the given text
- wait | milliseconds, to make the execution of the session wait for a given time
- clear cookies |, to make the browser of the session clear all of the cookies in it

## 4 Implementation

In this chapter I will describe the implementation of the language and the tool, the problems faced and the solutions adopted.

### 4.1 The tool

For the implementation of the Burp's tool introduced earlier, I have decided to start from a work done by my colleague Wendy Barreto [4] in her bachelor thesis, which realized a similar tool for OIDC and OAuth SSO protocols, this was a good base to start with my implementation. The interface of [4] has been taken and adapted to fit the needs of this work. The tool code is written in Java, I used the Burp's interface classes to interact with it. The standard usage of Burp Suite is based on the execution of a browser which connects to the Burp's proxy, in a way that all the packets can be intercepted, viewed or edited and forwarded or dropped from the Burp interface. The tester would do some actions on the browser and watch the flowing packets in Burp and then check them or edit them. With the tool the idea is the same, but the operation done on the browser and the checks or edits on the messages are made automatically, in a way that the tester doesn't have to do them by itself.

#### 4.1.1 Interface of the tool

In figure 4.1 we can see the interface of the tool, starting from top left we have the session track input space, where it can be specified a different track for each session. Following on the top right, we have a series of buttons that allow various configurations:

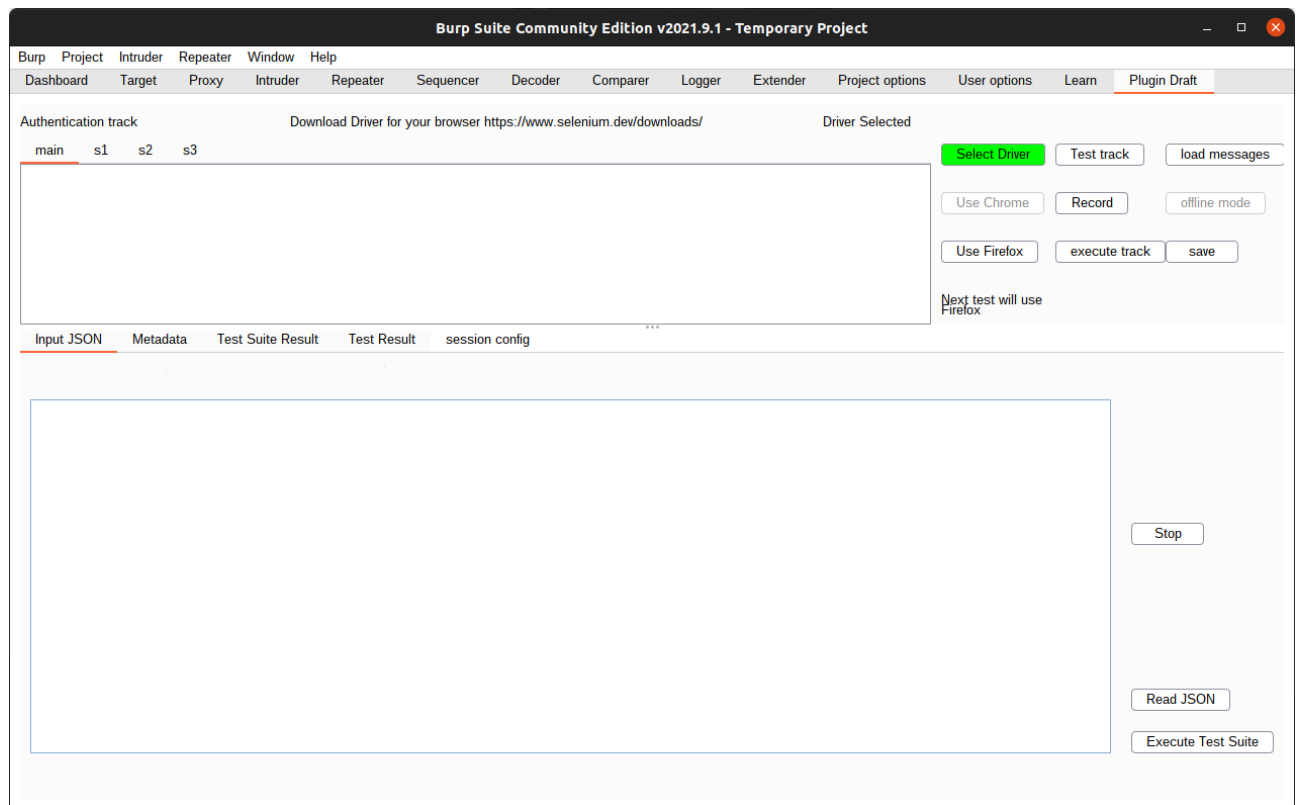


Figure 4.1: tool interface

- the browser to be used can be selected
- the driver to automate the actions on the browser can be selected
- the record button can be used to record the passing messages
- the load messages button can be used to load the previously saved messages to be tested "offline"
- the offline mode button to test the loaded messages instead of the live ones

In the bottom we have multiple tabs:

- "Input JSON" tab is used to load the tests written in the language into the tool, and with the use of two buttons we can parse the language and execute the tests.
- "Test suite result" is the tab containing all the results of the executed tests
- "Test result" is the tab used to see the specific test result, with all the intercepted messages related to it
- "Session config" is used to configure the ports of the sessions that will be used in the tests.

#### 4.1.2 Test execution

The test execution differs from passive to active, as passive tests don't need the edit of the messages, the execution of the session track is done once, the messages are saved and the tests are executed on the saved messages. I have also added the possibility of exporting the saved messages to a file, in a way that they can be imported in the tool and tested again. On the other hand, active tests need to edit the messages, so the execution of the track has to be repeated for each test.

### 4.1.3 Decoding & encoding of parameters

As said in the previous chapter, the decoding and encoding of parameters is possible. To do that, a list of encodings to be done on the parameter has to be provided, i.e. url, base64, deflate. Once the specified message is intercepted, the parameter is taken and decoded following the order of the provided encodings list. To do that, part of the code of SAML Raider [1] which did the decoding of SAML Requests and responses parameters has been used. I've taken that part of the code and edited it to fit the tool. SAML Raider is a Burp's plugin used to manage SAML certificates.

### 4.1.4 SAML certificate managing

In SAML Requests and responses there is sometime the need to remove or edit the certificate associated to that request or response, so, to speed up the process a specific tag in the language has been added to remove or edit the certificate signature. There is still the possibility of doing the same removal by editing the SAML request or response with a regex, but with the use of the tag is more convenient. In order to do this, a part of the code of SAML Raider [1] has been used, edited to fit my needs.

### 4.1.5 Oracle

To identify abnormal pages like error pages the session track evaluation should be sufficient, because if some of the actions could not be executed means that the original "flow" of pages was not followed.

### 4.1.6 Session managing

The sessions are managed independently, each session is basically a browser that is launched when a session is started. Each session can follow a different session track defined in the apposite tabs. Every session is runned in a separated thread to make parallelism possible. By the use of specific commands in the language, is possible to do some actions on each session, like stop it, pause it, or clear its cookies. Each browser uses a different proxy port, so that it is possible to know from which session the messages come from, and so, being able to specific sessions in the tests.

## 5 Uses cases

In this chapter some examples of use cases in which my work has been used will be shown.

### 5.1 SAML Use-Case

My work has been used by my colleague Sofia Zanrosso, for her bachelor thesis [16], her objective was to search for SAML vulnerabilities and to define a series of well-known test to verify them. She defined all the tests using my language and tested multiple SAML implementation with it. todo: talk of the tesis (when i have it)

### 5.2 OAuth & OIDC Use-Case

The OAuth and OIDC tests defined and used in [10][4] has been re-defined in the STL language and has been tested on some implementations of the protocols. todo: results

## 6 Related work

In this chapter other tools and works that are related to mine will be discussed.



## 6.1 Micro ID Gym

Micro ID Gym (MIG) "aims to assist system administrators and testers in the deployment and pen-testing of IdM protocol instances" - [9], inside this tool, two pentesting tool can be found:

- MIG - OAuth/OIDC [10]
- MIG - SAML SSO [8]

They are both plugins for Burp, which have as objective to test the two different protocols. These plugins execute a series of actions on a browser, and checks the messages in the background, then they tell a result. These two plugins are similar to mine, but they are specifically created and defined to test SSO protocols only, and the tests that they used are fixed and cannot be easily edited, if a new test has to be implemented, the plugin has to be recompiled.

## 6.2 SSO Testing language and Plugin

The preceding two plugins of MIG has been improved by a work similar to mine, the one done by my colleague Wendy Barreto [4] in her bachelor thesis at Università di Trento to test OAuth and OIDC SSO protocols with a custom test definition pattern. Her work aimed at fixing the problem of hard-coded tests in the plugins for SSO protocols testing. The plugin had been improved by removing the staticity of the test, adding the possibility to customly define all the tests with the use of a JSON language. The available test actions worked well, but there were some limitations on the possible actions, especially in the active tests. For example:

- Limited oracle for the verification of active tests, having just the verification of the correct execution of the operation and a check for the string "error" on the last page of the browser
- The filtering of which message to check or edit for static tests was limited: ( only "Authorization grant message", "Response messages", "Request messages" and "All messages")
- Only regex were supported to search something in a message
- Unable to work over encoded parameters
- Impossibility of doing multiple operations on a single message
- Impossibility of saving a parameter and using it somewhere else

Some of which stated as future works in Wendy's thesis.

Previously in this thesis I said that I have taken part of her work as a base to start with mine, editing it to suit my needs. The idea of a language that could be used for any type of test over HTTP was born when I used her plugin, which was limited to OAuth and OIDC tests. I wanted to enlarge the possible tests to be defined without a restriction on a specific protocol. One of the things that I used is the interface of her plugin, adding some buttons and tabs to deal with multiple session tracks and added functionalities. Also, the automation of the session track was taken and edited, it actually was already used in [10][8].

# 7 Conclusions, Limitations and Future Works

One of the biggest limitations that the tool has is the session track actions automations, it often happens that some captcha are encountered during execution, making impossible to proceed. Moreover, the track execution is limited, there is only a possible flow of actions (the one defined) and there is not the possibility of inserting if then else constructs that could help to differentiate the actions based

on the actual page or popup. For example, it could happen that an "limited time offer" popup could appear in a website only in a particular time, the execution of the session track could be compromised by that, making impossible to distinguish wether the test failed because of the tested vulnerability or the actual popup.

# Bibliography

- [1]
- [2] Katalon recorder sample plugin. <https://github.com/katalon-studio/katalon-recorder-sample-plugin>. Last accessed 19/11/2021.
- [3] Protecting mobile apps with pkce. <https://www.oauth.com/oauth2-servers/pkce/>, 2015.
- [4] Wendy Barreto. Design and implementation of an attack pattern language for the automated pentesting of oauth/oidc deployments. Master's thesis, Università degli Studi di Trento, 2021.
- [5] Brian Campbell, Chuck Mortimore, and M Jones. Security assertion markup language (saml) 2.0 profile for oauth 2.0 client authentication and authorization grants. *Internet Engineering Task Force (IETF)*, 2015. Page 2, Last accessed 29/11/2021.
- [6] Yulia Cherdantseva and Jeremy Hilton. A reference model of information assurance & security. In *2013 International Conference on Availability, Reliability and Security*, page 547. IEEE, 2013.
- [7] Milena Gabanelli e Simona Ravizza. Attacchi hacker, dati sanitari in pericolo: la lista segreta dei 35 ospedali colpiti. <https://www.corriere.it/dataroom-milena-gabanelli/attacchi-hacker-dati-sanitari-pericolo-lista-segreta-35-ospedali-colpiti/1abf2704-2079-11ec-924f-1ddd15bf71fa-va.shtml>, 2021. Last accessed 29/11/2021.
- [8] Stefano facchini. Design and implementation of an automated tool for checking saml sso vulnerabilities and spid compliance. Master's thesis, Università degli Studi di Trento, 2019/2020.
- [9] FBK. Micro-id-gym. <https://github.com/stfbk/micro-id-gym>, 2020. Last accessed 1/12/2021.
- [10] Claudio Grisenti. A pentesting tool for oauth and oidc deployments. Master's thesis, Università degli Studi di Trento, 2019/2020.
- [11] Dick Hardt et al. The oauth 2.0 authorization framework. <https://datatracker.ietf.org/doc/html/rfc6749.html>, 2012. Page 1, Last accessed 29/11/2021.
- [12] Giulio Pellizzari. Master's thesis, Università degli Studi di Trento.
- [13] Il Fatto Quotidiano. Attacco hacker lazio, al poliambulatorio santa caterina cittadini rimandati indietro: “impossibile fissare visite o cambiare medico”. <https://www.ilfattoquotidiano.it/2021/08/03/attacco-hacker-lazio-al-poliambulatorio-santa-caterina-cittadini-rimandati-indietro-impossibile-fissare-visite-o-cambiare-medico/6282342/>, 2021. Last accessed 29/11/2021.
- [14] Nat Sakimura, John Bradley, and Naveen Agarwal. Proof key for code exchange by oauth public clients. *Internet Engineering Task Force (IETF)*, *Published Sep*, 2015. Page 28, last accessed 11/12/21.
- [15] Wikipedia. Single sign-on. [https://en.wikipedia.org/wiki/Single\\_sign-on](https://en.wikipedia.org/wiki/Single_sign-on). Last accessed 29/11/2021.
- [16] Sofia Zанrosso. unknwon. Master's thesis, Università degli Studi di Trento, 2021.

# Attachment A Language comparison

## 1

Action	Old language	New language
Custom message filtering	Only on active tests	supported
Edit string	only by regex	supported with regex and check construct
Remove string	only by regex	supported with regex and check construct
Add string	not supported	supported
Check parameter	only with regex	with regex and check construct
Multiple operations in single message	not supported	supported
Saving and reusing of values and messages	not supported	supported
Multiple sessions in single test	not supported	supported
Custom oracle definition	not supported	by using regex and checks

# Attachment B PKCE test Example complete

This is the complete PKCE test example

```
1 {
2   "test suite": {
3     "name": "OAuth Active tests",
4     "description": "A series of tests to test OAuth's well-known
↪ vulnerabilities",
5     "filter messages": true
6   },
7   "tests": [
8     {
9       "test": {
10        "name": "PKCE Downgrade",
11        "description": "Tries to remove code_challenge parameter",
12        "type": "active",
13        "sessions": [
14          "s1"
15        ],
16        "operations": [
17          {
18            "session": "s1",
19            "action": "start"
20          },
21          {
22            "action": "intercept",
23            "from session": "s1",
24            "then": "forward",
25            "message type": "authorization request",
26            "preconditions": [
27              {
28                "in": "url",
29                "check param": "code_challenge",
30                "is present": true
31              }
32            ],
33            "message operations": [
34              {
35                "from": "url",
36                "remove parameter": "code_challenge"
37              }
38            ]
39          }
40        ],
41        "result": "incorrect flow s1"
42      }
43    ]
44  }
```

