

Best Practice Authentication and Authorization

in distributed Business Scenarios with OpenID Connect and OAuth 2.0

Master Thesis

submitted in conformity with the requirements for the degree of

Master of Science in Engineering (MSc)

Master's degree programme **IT & Mobile Security**

FH JOANNEUM (University of Applied Sciences), Kapfenberg

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August 2018

**Assignment for the master thesis of
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**Subject:
“Best Practice Authentication and Authorization”**

Abstract

Write your abstract here.

Kapfenberg, <date>

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Acknowledgement

Thanks to ...

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Introduction

With the rise of social networks, online services experienced a revolution quite recently and thus have had a significant impact on the way private information gets propagated on the Internet. Developers split up solutions into backend and frontend applications and build their backend solutions as Application Programming Interfaces (API) which can be used to propagate services online. Published APIs can then be consumed by frontend applications or even third-party applications. This approach especially gained popularity with the rise of mobile and single page applications, which heavily depend on a light-weighted frontend. However using APIs to access the business logic means, that the trust relationship is not between two parties but also may include third-party applications. This uncertain trust relationship raises concerns of users and developers regarding security and privacy of personal information. Building trust is a substantial part for architects and developers when designing a system. In order to efface security and privacy concerns of users an advanced access and identity management system is needed. [cf. (Cirani et al., 2015), (Tkalec, 2015), (Røssvoll, 2013)].

1.1 Problem Statement

In traditional architectures, a third party receives the user's credentials for the user to be able to access information from the third party as stated before. Prasad, 2016 however points out that sharing the credentials with a third party might lead to security problems. Third parties might be responsible for fatal security gaps, for example by storing passwords in plain-text. *ibid.* further states that the compromise of one third-party will then lead to the compromise of the credentials of the end user. As a result, the safety of the secure resources cannot be granted anymore. Moreover, third-parties

will receive the comparatively more significant amount of access to the user data than needed. Another concern is pointed out by Sakimura, Bradley, Jones, Medeiros, et al., 2014, which is that users often are required to create new accounts for each service they want to use. On the one hand the process of creating a new account for a service can be annoying for the user because they have to burden of keeping track of multiple accounts and remembering multiple credentials. On the other hand the complex task of managing this accounts can led to problems like password fatigue and in the worst case to identity theft or the compromise of services [cf. (ibid.), (Prasad, 2016)].

This common problems with a modern application setup, where the backend application is represented by an API, lead to the question, what is the best way to secure these applications and which of the existing approaches is best for a particular case. Furthermore what risks come with the use of a certain approach and what is the state of the privacy.

1.2 Research Question

What are feasible ways to implement authentication and authorization for enterprises that depend on adaptability and focus on modern single page applications? How can businesses find out with identity management system is best suited for their use case? Furthermore, what are benefits of the token-based authentication with OAuth2 and OpenID Connect versus traditional authentication methods? These questions should be elaborated while considering common security risks of modern web applications.

1.3 Hypothesis

In modern architectures, a third party often is responsible for the implementation of the process of authentication and authorization of the user. Considering the setup of a company and the use case of the authentication and authorization of users, the requirements towards identity management can be very different. Grassi, Garcia, and L., 2017 suggest for identity management, to rely on standards and specifications that are widespread and documented. Example for tools and standards include Internet protocols for accessing services like REST, SOAP, and XML and federate identity standards for service authentication such as SAML, OAuth, and OpenID Connect.

In this thesis, the focus is on modern distributed architectures and ways to provide

users secure access to protected resources and confidential management of the user's credentials for a specific scenario. The question to be answered is what kind of identity management system is best suited for a use case to reduce common identity threads

1.4 Method

In order to prove the described hypothesis the following method is applied:

- Acquire knowledge about authentication and authorization methods
- Analysis of risks based on a use case
- Develop a best practice example

The priority was to make extensive research on the topic to get an overview of the current state of authentication and authorization methods. After the research before starting to analyze the different methods of authentication and authorization, a case for an assessment is defined and described in detail. Based on this case a risk assessment is executed and the according to the level of assurance is a deterrent. The level of assurance need for this case allows choosing the appropriate technologies to mitigate risks and the impact of errors. With this set of technologies and example solution for a modern enterprise single page application is created to give a best practice example based on the theatrical gathered knowledge.

Related Work

"On the Internet, nobody knows you are a dog"(Steiner, 2018)

The cartoon of *ibid.* showing two dogs sitting in front of a computer with the iconic title cited above became an illustration of how people view anonymity on the Internet. Being anonymous on the Internet, however, is not that easy anymore. The use of mobile devices has changed the way how we access information, interact with each other and share content. Digital services are used to access information, which is opening fraught opportunities to attackers who are trying to impersonate someone and access confidential information. With this change of user behavior, the way we think of authentication and authorization methods has to adjust. Identity management is mandatory to provide a seamless user experience, including identity proofing, authentication, and assertions in federated environments [cf. (Grassi, Garcia, and L., 2017), (Corre et al., 2017)].

Users find themselves struggling using multiple devices, accounts, and services. The user's burden of this site-by-site account management is putting security at risk. The goal of new authentication and authorization solutions is to help the user managing his accounts by providing single-sign-on, based on an exchange of identity-related assertion across security domains in a scalable way [cf. (*ibid.*)].

In this related work part existing work and methods to authenticate and authorize users a described. The part is split up in the chapters Security Considerations, Identity Proofing, Authentication, Assertion, Popular Federation Systems, Token-based Authentication and Single Sign-On.

2.1 Security Considerations

Before getting further into the topic of authentication and authorization, this section will shed light on some basic security principles, concerning authentication and authorization, which help to understand the need for authentication and authorization mechanisms.

Some basic design principles formulated by Saltzer and Schroeder, 1975 in 1975 were paraphrased by Neumann, 2013 and are still relevant today. The principles give an underlying overview of what should be the focus when designing a secure system. The first of the ten basic security principles formulated by Saltzer and Schroeder, 1975 is the economy of mechanism which means to keep the design as simple as possible. The next principle describes that access should not be explicitly denied instead it should be explicitly permitted. For example, when using Access Control Lists (ACLs), all access should be explicitly denied by default. This kind of access control is called Fail-safe defaults. Furthermore, *ibid.* states the complete mediation principle, which every access to every object has to be checked for authority without exceptions. A fundamental concept that is part of these ten principles is an open design. The design of an application should not be secret. It can not be assumed that design secrecy will enhance security. This principle is applied in cryptography. The design of cryptographic algorithms is available for the public; just the keys remain secret. A broadly used principle in authentication is the separation of privileges. Separation of privileges means that two keys should be used to protect resources if feasible and privileges should be separated. Furthermore, every application and user should be provided with least privileges they need to complete their job. The existence of overly powerful mechanisms such as superuser is inherently dangerous - this is called least privilege. The least common mechanism principles compel to minimize the amount of mechanism common to more than one user and depended on by all users. In authentication users often get frustrated with the complicated sign-in processes. Therefore, the psychological acceptability should be kept in mind. Keep it simple. The design of the interface for the user should be easy to understand so that the user routinely and automatically applies the protection mechanism correctly. The attack factor or work factor how *ibid.* is essential to protect sensitive resources. Cost-to-protect should commensurate with threats and expected risks. It should not be possible to circumvent the mechanism with the resources of the attacker. The last one is a recording of compromises which means to provide trails of evidence which are tamper-proof and difficult to bypass. All of these principles are important when choosing an authentication system and need to be considered carefully.

Besides formulating these fundamental principles which will be discussed in various forms, Saltzer and Schroeder, 1975 also discuss the terms "privacy" and "security". Those terms get frequently used by authors writing about information storing systems, like in this paper. However, the terms "privacy" and "security" are often used very differently. *ibid.* for example, defines "privacy" as the ability of an individual to specify whether, when and to whom sensible information is released, and "security" is described as a technique that can control who can modify resources on a computer. Another more recent description of the terms "security" and "privacy" comes from Brooks et al., 2017. *ibid.* state the importance of the distinction between privacy and security. This distinction is between privacy and security are essential because there are security issues unrelated to privacy, just as there are privacy issues that are unrelated to security. While security concerns arise from illegal system behavior, privacy concerns arise from byproducts of authorized personally identifiable information (PII) processing. Even byproducts that are considered to protect PII can raise security concerns, for example, it can be questioned to which degree a tool for persistent activity monitoring should reveal information about individuals that are related to security purposes. However, security and privacy have in common that they want to protect personal information and resources or PII [cf. (*ibid.*), (Saltzer and Schroeder, 1975)].

These security issues and privacy issues, of course, raise particular concerns for users as well as for companies offering authentication services. When it comes to protecting personal resources, there are three primary concerns. According to Todorov, 2007 those three concerns are Confidentiality, Integrity, and Availability. The term confidentiality means that personal information is protected from disclosure to unauthorized individuals and organizations. Integrity or integrity of information is protecting information from accidental or intentional tampering. Modification of confidential data may affect the data validity. Availability is the need to be able to access information at the time a user requests it. The availability of the services that exposes information has to be given as well. In an ideal world companies offering authentication and authorization services will do everything to use the best technologies regarding countermeasures to protect confidentiality, integrity, and availability. Establishing countermeasures, however, can be costly leading to a trade-off between costs and level of production of information. A typical approach to establishing information security management is to analyze risks first and then form counter measurements [cf. (*ibid.*)].

Grassi, Garcia, and L., 2017 splits the risk assessment into different sections, rather than combining proofing, authentication, and federation of digital services into a single Level of Assurance(LOA). In order to provide the most effective approach each of the section is analyzed regarding risk and impacts of failure. The assessment should help to

avoid errors and choose based the results which technologies and mitigation strategies should be chosen. Errors that can be avoided with an extensive risk assessment are identity proofing, authentication and federation errors. Identity proofing risks include a malicious applicant successfully poses as someone else or for example the impacts of collecting more information about an applicant then required. Choosing the right level of assurance in the identity proofing process gives robustness and confidence to the determination of identity. The right authentication assurance level is chosen to mitigate problems in the authentication process, and the binding between an authenticator and a specific individual. An example of a potential error is the applicant may use credentials that not rightfully belong to them. Moreover, last but not least the accurate federation assessment helps to mitigate potential federation errors. Federation errors might occur when an identity assertion is compromised. Analyzing this risk makes it easier to choose an assurance level for each category. Therefore, the risk gets categorized of harm according to Grassi, Garcia, and L., 2017:

- Inconvenience, distress, or damage to standing or reputation;
- Financial loss or agency liability
- Harm to agency programs or public interests
- Personal safety
- Civil or criminal violations

Each of the categorize can then be rated with a potential impact level which can be either low, moderate and high. The result of this risk assessment can then be the basis for choosing the appropriate identity, authentication and federation assurance level. The assurance level determination is just relevant for analyzing the risk of online transaction offered by digital services and should not be used for the complete business process which may include offline processing in a entirely segmented system.

The result of all design principles, security and privacy considerations should be a system, network or component that is trustworthy. According to Neumann, 2013 trustworthiness is given if an entity satisfies its specified requirement, after a reliable assessment. The requirements that deserve especially consideration are, those that are critical to an enterprise, mission, system, network or other entity. One of the requirements to make a system trustworthy is a reliable authentication and authorization process. These processes are discussed in more detail in the next sections.

2.2 Identity Proofing

“Digital identity is the unique representation of a subject engaged in an online transaction. The process used to verify a subject’s association with their real-world identity is called identity proofing” (Grassi, Garcia, and L., 2017)

A digital identity as explained above is the result of what is called the authentication process. It is a way of identifying the user as whom he claims to be. In order to proof the users identity presentation, validation and verification of a minimum set of attributes is necessary [cf. (Boyd, 2012)].

To become an authenticated the user has to go through certain steps on the way. These steps the user has to go through are enabled by typical components unique to the authentication process. Todorov, 2007 identifies three typical components that are part of the authentication the Supplicant, the Authenticator and the Security Database. The Supplicant is the party that provides the evidence to prove the identity of a user or client. The result of the authentication process should be the authenticated user or client. The Authenticator, also called server, is responsible for ascertaining the user identity. After prove of identity, the authenticator can authorize or audit the user access to resources. Security Authority Database, which is storage or a mechanism to check the user’s credentials. The storage can be represented by as much as a flat file, a server on the network providing centralized user authentication or a distributed authentication server [cf. (ibid.)].

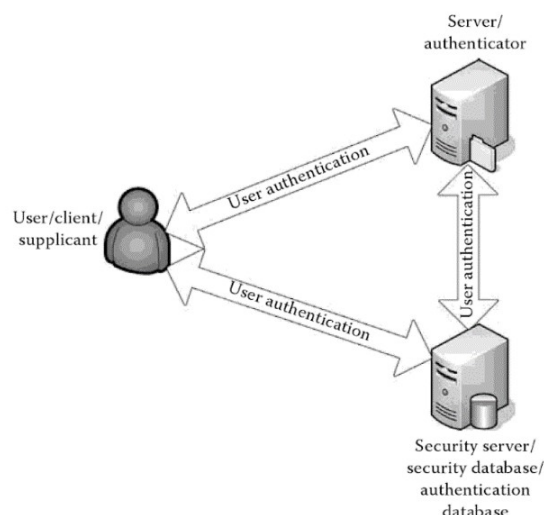


Figure 1.1 Components of a user authentication system.

Figure 2.1: Components User Authentication System

It is vital that all the components like shown in (figure 2.1), of a user authentication system can communicate independently of each other. Whether or not all communication channels are used depends on the authentication mechanism and the model of trust that it implements. For example, the Kerberos authentication protocol does not feature direct communication between the authenticator and security server [cf. (Todorov, 2007)].

Grassi, J. L. Fenton, et al., 2017 also describes components that are similar to the ones described by Todorov, 2007 in (figure 2.1). Furthermore Grassi, J. L. Fenton, et al., 2017 describes additional expectations of the identity proofing process. The expected outcome of the identity proofing process should be that the claimed identity is linked to a single, unique identity, whereas the provided evidence for the claimed identity has to be validated to proof it is correct, genuine and exists in the real world. Furthermore *ibid.* describes three different identity assurance level shown in 2.1 Identity Assurance Levels.

Identity Assurance Level	
IAL1	There is no need to link the applicant to a real-life identity. All attributes provided are self asserted and are neither validated nor verified.
IAL2	The evidence provided supports the real-world existence of the claimed identity. The identity proofing has to be either remote or physical present.
IAL3	The identity proofing requires physical presence. Attributes must be verified by a authorized and trained CSP.

Table 2.1: Identity Assurance Levels (Grassi, Garcia, and L., 2017, p.18)

2.3 Authentication

For a very typical authentication process, the user provides its username and password when the application demands it. If the user provides a correct username and password, an application assumes the user is indeed the owner of the account he wants to log on. The evidence provided by the user in the authentication process is called credentials. Most of the time as mentioned above credentials get provided in the form of username

and password. Nevertheless, credentials also may take other forms like PIN's, key cards, eye scanners and so on [cf. (Todorov, 2007), (Boyd, 2012)].

Credentials, which prove the identity of an entity and find use as authenticators in authentication systems, are called factors. Grassi, Garcia, and L., 2017 categorize following types of factors:

- Something, the user, knows - Cognitive information the user has to remember. Examples include passwords, PIN, answers to secret questions.
- What the user has - something the user owns. Examples include a security token, driving license, one-time password (OTP). What the user is - biometric information of the user. Examples include fingerprint, voice, and face.
- What the user is - biometric information of the user. Examples include fingerprint, voice, and face.

Other types of information which are not considered authentication factors but can be used to enrich the authentication process according to Dasgupta, Arunava, and Abhijit, 2017 are:

- Where the user is - the location of the user can be used as a fourth factor of authentication. Examples include GPS, IP addresses.
- When the user logs on - Time can also be extracted as a separate factor. Verification of employee's identification in different office hours can prevent many kinds of grave data breaches. The time factor can easily prevent online banking fraud events to a great extent.

The authenticators are based on secrets that can be either public key pairs (asymmetric keys) or shared secrets (symmetric keys). Public key pairs consist of a private and a public key. The private key gets stored on the authenticator, the holder of the private key can use it to prove that he controls the authenticator. The verifier of the authenticator can then use the public key - most likely received with the help of a public key certificate - together with the authentication protocol to verify the identity of the user. Shared secrets can be either symmetric keys or memorized secrets. Both keys and passwords can be used with similar protocols. However, there is a huge difference for the user. Symmetric keys are generally stored on hardware; secrets have to be memorized by the subscriber which can lead to multiple vulnerabilities. The user chooses short, memorable passwords while cryptographic keys are typically long enough to make network-based guessing attacks untenable user-chosen passwords may be vulnerable [cf. (Grassi, Garcia, and L., 2017)].

To secure a solution properly, it should at least use two factors of the three listed above. To make use of more than one factor of a pool of potential credentials to verify the identity of a user is referred to as Multi-factor Authentication (MFA). The goal of multi-factor authentication is it to provide a layered defense and make it harder for unauthorized individuals to gain access. If one of the factors breaks, the service can still rely on the non-compromised authentication factors [cf. (Dasgupta, Arunava, and Abhijit, 2017)].

Using just one factor is called Single Factor Authentication(SFA). *ibid.* clearly describes the drawbacks SFA has compared to MFA, primarily the universal used password-based authentication. The user needs to remember different passwords for multiple accounts. Therefore, the user often reuses one password also known as password fatigue.

In an Interview by Tomkins, 2009 with Jon Brody, he explains Password Fatigue like the following. An average user has 15 accounts; some people might even have up to 30 accounts - far too much to manage appropriately. Users then tend to adopt specific password patterns like using simple passwords for nontransactional sites and complex passwords for banking sites. Since many complex passwords are hard to remember users also often reuse passwords for different services at one point - this is called password fatigue.

Besides password fatigue Todorov, 2007 draws attention to one of the significant challenges of secure user authentication represented by default passwords. Vendors often ship their devices with pre-configured standard passwords. Although vendors recommend changing default passwords, system architects and engineers often fail to do so because they are more focused on the business logic than on security causing security issues. Systems with default passwords are more straightforward to attack, for example by knowing or guessing the device the attacker has an easy time authenticating with the system accordingly.

Due to the problem of password fatigue and default passwords, one factor like a password might easily get compromised. The user can then no longer use the service until the repair of the system which can lead to a delay of the user when trying to access necessary information. Also, there is a risk that the user does not notice the compromise of the single factor which can lead to devastating effects [cf. (Dasgupta, Arunava, and Abhijit, 2017)].

When designing an authentication process by using multiple factors the designers of the process should be acutely aware of the type of application and the information that has to be secured. For example, a solution for an international bank should have differ-

ent standards than an app for a making a grocery list. On the one hand, challenging and complex authentication processes for trivial applications might scare away users. On the other hand, simple methods for applications protecting sensitive data might drive users away as well. Application designers should always try to find a middle way that suits both parties, the application owners and the users [cf. (Grassi, Garcia, and L., 2017)].

Grassi, J. Fenton, et al., 2017 defines three different authenticator assurance levels to make sure the system a company is designing uses the appropriate authenticators for their purpose. Each of the authenticator assurance levels has to fulfill all the requirements of their successor. *ibid.* describes three levels shown in 2.2 Authenticator Assurance Levels.

Authenticator Assurance Level	
AAL1	The first level defines that a claimant has to provide some kind of assurance that he controls an authenticator bound to a subscribers account through a secure authentication protocol. The guarantee can be either in the form of a single-factor or multi-factor authentication.
AAL2	The second level requires the use of at least two distinct authentication factors. The confidence that the claimant controls the authenticators of the subscriber's account is high at this level. Appropriate cryptographic techniques are required.
AAL3	The third level provides a very high level of confidence that the claimant is in possession of the authenticators bound to the subscriber. Claimants need to prove possession of the key with two distinct authenticators through a secure authentication protocol. One of the authenticators needs to be hardware-based.

Table 2.2: Authenticator Assurance Levels (Grassi, Garcia, and L., 2017, p.19)

To reflect on authentication, it can be said that authentication is a critical part of every application. As users are getting more concerned on security, the pressure on developers grows to provide a solution that secures sensible data while keeping up usability standards, which can often be a trade-off. Complex applications need complex security which can mean high costs for individually developed solutions; therefore application developers should also think about using federated authentication solutions.

2.4 Assertion

The authentication and authorization process are very closely related to each other and for users often hard to separate. After the authentication process of a user, the application has now proved that the user is whom he claims to be, but not every user is the same. After the user authenticates, the user may want to access data or services. Based on the information provided by the authentication process the application can allow or deny the user to access information or services. In other words, we have to check if the user is authorized to access data of a service. Furthermore, authorization offers granular control to distinguish between reading, write or execute access to individual resources, typically access control list (ACL) are used for each operation [cf.(Todorov, 2007, Boyed, 2012)].

Systems offer a user login process or sign-in process, in order to receive the information necessary to make authorization decisions. The login process initiates the authentication process between the user and the system. As a result of this process where the user has to prove its identity, the user receives a system or application specific structure. In a federated identity system, this is called an assertion. The assertion holds an identifier and identification information about the user which can indicate for example what kind of resources the user can access. For every action, the user then has to provide the assertion and based on the information provided within the assertion the user is then either granted or denied access. Another example of the usage of the assertion is the personalization of websites [cf. (Todorov, 2007), (Grassi, Garcia, and L., 2017)].

In federated systems, the verifier of authentication information of the user is called Identity Provider (IdP), and the party that receives and uses information is called the Relying Party(RP). In the context of the federated identification systems the user, or the one that is trying to access information from a system is called the subscriber. The IdP generates an assertion for the verifier associated with the subscriber. This process allows subscribers to access multiple RPs without maintaining separate credentials and the process also supports single-sign on. Grassi, Richer, et al., 2017

Grassi, Garcia, and L., 2017 defines different levels of federation assurance that define how assertion should be constructed and secured for a given transaction. Each successive level has to fulfill the requirements of all lower level. Federation assurance levels defined by Grassi, Richer, et al., 2017 are shown in 2.3 Federation Assurance Levels.

For any assertion level, the IdP has to make sure that an RP cannot impersonate the IdP at another RP by signing the assertion. The signing of the assertion can be done by either a MAC using a shared key or a digital signature using an asymmetric key [cf.

Federation Assurance Level	
FAL1	The first level requires a bearer assertion, signed with approved cryptography by an IdP, for example, OpenID Connect Basic Client profile or Security Assertion Markup Language (SAML) Web SSO Artifact Binding profile with no additional feature.
FAL2	The second level requires an assertion like the OpenID Connect ID Token or SAML Assertion, to be encrypted with the public key of the RP, whereas the RP is the only party that can decrypt the bearer assertion.
FAL3	Additionally to the first two levels the last federation assertion level requires the subscriber to prove that he is in possession of a key that is bound to the assertion (holder of key assertion) and initially was used to authenticate to the IdP.

Table 2.3: Federated Assurance Levels (Grassi, Garcia, and L., 2017, p.19)

(Grassi, Garcia, and L., 2017), (Grassi, Richer, et al., 2017)].

One of the factors that differentiates federation assurance level is the usage of assertion binding. An assertion binding can be chosen based on the RP requirements of rather the RP needs additional proof of the binding of an assertion to a particular subscriber. The two different kind of assertion binding to chose from is the bearer and holder-of-key assertions. Any party can present a bearer assertion in order to prove to have the identity of the bearer. Based on this handling of bearer assertions it can be assumed, that if an attacker is successful in capturing a bearer assertion, he can represent the subscriber that was previously associated with this bearer assertion. The attacker could present the assertion or reference to the RP and impersonate the subscriber. The holder-of-key assertion in comparison holds a reference to a key which indicates which subscriber is representing the assertion. The key is signed and asserted by the issuer of the assertion [cf. (ibid.)].

Typically tokens are used for assertions, in this contexts tokens are software tokens which are used to provide access control for systems. The assertion binding described before can also be referred to as token profiles. Typically there are two kind of tokens that are frequently used, which is the access token and the refresh token. An access token, when it is valid can be used to access resources. If the access token is expired and not valid anymore and refresh token can be used to reclaim a new access token.

OpenID Connect additionally defines an ID token which will be discussed later [cf. (Spencer, n.d.)].

Furthermore tokens can be passed either by reference or by value. On the one hand if a tokens are passed by reference they have to be resolved at another instance. On the other hand a token can be passed by value and already has all the necessary information about the user to establish for example a session. Those two ways of passing a token are very important when it comes to security considerations. Also token have different types. The OAuth specification for example does not specify which kind of token has to be used. *ibid.* list some of the typical tokens:

- WS-Security token (SAML)
- JWT tokens
- Legacy tokens
- Custom tokens

In praxis developers often use JSON Web Tokens because they are very flexible and allow to add additional claims. Also they use JSON and not XML like SAML tokens, which is much easier to process. More about JSON Tokenens can be read in the upcoming chapter Token-base Authentication [cf. (*ibid.*)].

2.5 Token-based Authentication

The way web developers write back-end applications has changed significantly with the rising popularity of single page and mobile applications. Backend-developers no longer spend a lot of time building markup. Instead, they build APIs for front-end applications to consume. The split up of front-end and back-end allows the back-end to focus on business logic and data management while the front-end solely focus on the representation of the content. The number one way single page and mobile web applications are authenticating users according to Tkalec, 2015 is token-based authentication.

Sevilleja, 2015 shares the view that token-based authentication is the modern way to handle authentication. Token-based authentication should be considered because of various factors. It is optimal for mobile applications which work in a stateless way and need to adapt to the sudden change of demand in a scalable way. Furthermore, token-based authentication provides extra security and applications can pass on au-

thenticated users to other applications. However, before taking a closer look at token-based authentication, it should be taken into account how Sevilleja, 2015 and Tkalec, 2015 concluded that token-based authentication is the best alternative for modern web applications to authenticate their users. Therefore, Sevilleja, 2015, for example, examines how authentication was done in the past. One approach to authenticate users used in the past that puts token-based authentication in perspective is server-based authentication.

2.5.1 Server-Based Authentication.

A lot of modern-day API's built on the Representational State Transfer (REST) programming paradigm which basis is the HTTP protocol which is stateless as well. A protocol that is stateless does not recall the actions that were taken beforehand which mean for example that if we authenticate the user, in the next request we have to authenticate the user again because the application will not know the user anymore [cf. (ibid.)].

The aim of server-based authentication is for the application to remember the user that logged on at the application. The application has to store the information on the server, which can be done in a few different ways on the session, usually in memory on the disk. The workflow of a server-based authentication starts with the server delivering the website and the user logging in with username and password. The server saves the information from the user login info in a session. After the session is established, the session is checked on the server for every request. If the session is valid, the server returns the requested data to the server. However, since modern single-application and mobile applications are on the rise, this method to authenticate user shown some problems, especially when it comes to scalability [cf. (ibid.)].

The session handling with server-based authentication is especially hard on the server's bandwidth. Most of the time the session gets established in memory on the server when the user authenticates. This approach leads to an enormous overhead. The second problem with this approach is that the information of the user is held in memory on the server. Since more and more companies are moving servers to the cloud, this is not only a security issue but replicating servers to scale is limited. Also nowadays users want to access their data at any moment from every device. Providing the user with the possibility to access data across multiple mobile devices is vital, which means cross-origin resource sharing has to be enabled. With server-based authentication, it is possible to run into problems with the forbidden request when the user tries to access

data from another domain [cf. (Sevilleja, 2015)].

2.5.2 Token-based authentication with JSON Web Token

The most important thing about token-based authentication is that it is stateless, much like HTTP. The server does not have to hold the session of the user over an extended period on the server. Instead, the user can request resources by offering a token generated by an authentication server. The token send in the query string or Authorization header can then be validated at the resource server, and the secure resource will be returned to the user. The approach of using JSON Web Tokens gives one the ability to scale applications without considering on which domain the user logged on. Another advantage besides being scalable is that token-based authentication gives one the possibility to reuse the same token for authenticating the user. Therefore, it gets easier to build applications that share permission with other application because many separate servers, running on multiple platforms and domains can reuse the same token. The approach also gives performance advantages compared to server-side authentication because there is no need to find and deserialize the session on each request. However, since it is best practice to encrypt the token, the token still needs to be validated, and the content needs to be parsed. One way to implement token-based authentication is with the help of JSON Web Tokens. JSON Web Tokens are gaining popularity fast and are backed by huge companies like Google and Microsoft. Also, the Internet Engineering Task Force defines a standard specification. OpenID and OAuth also use the JSON Web Token as a standard; therefore, the usage of the JSON Web Token will be explained in detail [cf. (Tkalec, 2015)].

JSON Web Token (JWT) is a compact structure that holds information about the authentication of a user or claims. The structure is indented for space-constrained environments such as HTTP Authorization headers. The payload of the JSON Web Token is of JSON, enabling the claims to be digitally signed or integrity protected with a Message Authentication Code (MAC) and encrypted [cf. (Jones, Bradley, and Sakimura, 2015)].

The standard is used to transport data between interested parties. The transferred data can be for example the identity of a user or user's entitlements. Furthermore, with the possibility of digital signatures and encryption data can be transferred securely over an unsecured channel. The signatures also allow asserting the identity of a user if the recipient trusts JWT is asserting party [cf. (Siriwardena, 2016)].

An example of a JWT Token is an id_token. Google provides for Developers an OAuth

encoded values. The different values are separated by a (‘.’) character. How many parts a JWT has is dependent on how the JWT is serialized. Either by using the JWS Compact Serialization or JWE Compact Serialization [cf. (Jones, Bradley, and Sakimura, 2015)].

To make sense of this JWT token in the figure above it is best to look at each of the three parts of the JWT separately. When decoding the first part of the JWT, we receive a JSON object. Each part can be decoded individually but if a quick representation of a token is needed developers are the best advised to use <https://jwt.io/>. The website not only decodes the information of the token it also verifies the token. The figure above shows a warning that pops up if the token is not flawless. The verification of the token and the signing is done with multiple libraries that inform about certain vulnerabilities of the JSON Web Token. The first decoded part of the JWT gives us the following JSON.

```
1 {  
2   "alg": "HS256",  
3   "typ": "JWT"  
4 }
```

Listing 2.2: JOSE Header

The JSON object in 2.2 is the JOSE Header, representing the type of the token, the cryptographic operations applied and optionally additional properties of the JWT. Based on the information of the JOSE Header it can explain if the JWT is a JWS or a JWE. When speaking of JWT, we speak of one of the implementations of JWT because in fact, JWT does not exist itself. Concrete implementation of the JWT is JSON Web Signature (JWS) or JSON Web (Encryption). The figure below gives an optical representation of the structure [cf. (Siriwardena, 2016)].

The ‘type’ Header Parameter we can examine in 2.2 indicates the kind of token, considering the example it is a JSON Web Token. The second parameter is the ‘alg’ Header Parameter and is specified in either the ‘JSON Web Security (JWS)’ reference documentation written by Jones, Bradley, and N., 2015 or the JSON Web Encryption (JWE) reference documentation written by Jones and Hildebrand, 2015. In this case, the JWT is a JWS since a JWE needs more specific Header Parameter. In the JWS the ‘alg’ Header Parameter gives information about the algorithm which was used to create the signature. Which kind of arguments are accepted by the ‘alg’ Header Parameter are explained in yet another specification called ‘JSON Web Signature and Encryption Algorithms’ written by Jones, 2015. In the example 2.2 the ‘HS256’ algorithm is used, meaning that the JWS was MACed using the HMAC SHA-256 algorithm.

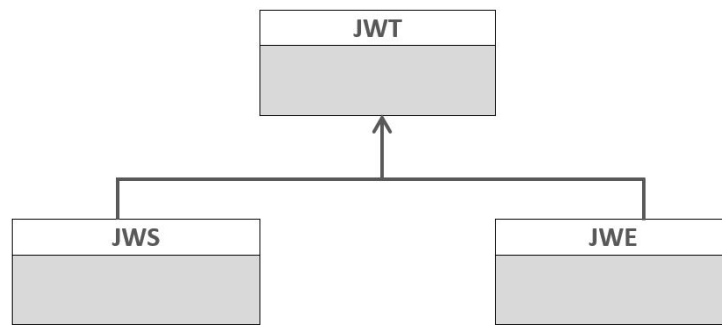


Figure 2.3: JWT Inheritance

The definition of the 'alg' Header Parameter in the 'JSON Web Signature (JWS)' reference documentation is very similar to the definition in the 'JSON Web Encryption (JWE)' reference documentation except the cryptographic algorithm is used to encrypt or determine the value of the CEK. Jones and Hildebrand, 2015 also defines an 'enc' Encryption Algorithm Header, which is used for content encryption on plaintext. The authenticated encryption performed produces a ciphertext and the authentication tag. Also for the 'enc' Header Parameter, the valid arguments can be found in the 'JSON Web Signature and Encryption Algorithms' written by Jones, 2015. The algorithm used must be an AEAD algorithm with a specified key length. There is further Header Parameter that can be defined, here are just the most essential JOSE Header Parameter for this document listed.

The second decoded part of the example in 2.1 JWT Token, represents the claim set. The representation of the claim set is a JSON, where each key has to be unique. If the keys are duplicated one can either end up with a JSON parsing error or the last one of the duplicated keys is returned.

```

1 {
2   "azp": "407408718192.apps.googleusercontent.com",
3   "aud": "407408718192.apps.googleusercontent.com",
4   "sub": "112301938322810239712",
5   "email": "corneliarauch@gmx.at",
6   "email_verified": true,
7   "at_hash": "Rv2QB6hg1jt6QhtIXneieg",
8   "exp": 1529747196,
9   "iss": "https://accounts.google.com",
10  "iat": 1529743596,
  
```

```

11 "name": "Conny Rauch",
12 "picture": "https://lh4.googleusercontent.com/-bElKwh5Z5Bg/
13 AAAAAAAAAAI/AAAAAAAAABNk/JyBmWMonaII/s96-c/photo.jpg",
14 "given_name": "Conny",
15 "family_name": "Rauch",
16 "locale": "de"
17 }

```

Listing 2.3: Claim Set

The decoded value from the example in Listing 2.1 of the Google OAuth 2.0 Playground Inc., 2018 returns a JSON object shown in the Listing 2.3. The claim set we receive is composed of mandatory and optional claims. Specifically requested in this example were the login, email and profile scope which affected the claims returned from the Google OAuth 2.0 API. Mandatory claims for the login with OpenID are iss, iat, aud, sub and exp and an optional claim that was returned from the API is azp. This claims will be discussed in more detail in the chapter on OpenID and OAuth 2.0. For the profile scope, the specific claims that were returned are name, picture, given_name, family_name, and locale. Email specific claims are email and email_verified. Furthermore, identity providers can include additional elements that are neither mandatory or optional claims [cf. (ibid.), (Siriwardena, 2016)].

The last and third part from the example in Listing 2.1 represents the base64url-encoded signature. To know which kind of signature the decoded code is resembling a peek at the JOSE Header will help. The JOSE Header as mentioned before gives information about the cryptographic elements that were used related to the signature. In case of Listing 2.4 the Google OAuth 2.0 API uses RASSSA-PKCS1-V1_5 with the SHA-256 hashing algorithm. However the <https://jwt.io/> website does not provide us with the decoded public key.

```

1 {
2 RSASHA256(
3 base64UrlEncode(header) + "." +
4 base64UrlEncode(payload),
5 Public Key or Certificate.
6 )
7 }

```

Listing 2.4: Signature JWT

To serialize an encrypted message, one has to follow either the JWS or the JWE specification. Each of the specifications has the type's compact serialization and serialization.

Google OpenID Connect uses the compact serialization. In fact, the OpenID Connect specification suggest using the JWS compact serialization or the JWE compact serialization. In this paper only the compact serialization will be discussed, the specification of the other serialization method can be either looked up in the JWE specification or the JWS specification. To call a JWS or a JWE, a JWT it has to follow the compact serialization [cf. (Jones, Bradley, and N., 2015), (Jones and Hildebrand, 2015)].

The aim of the JWS Compact Serialization is it to present content as a compact, URL-safe string, which is either digitally signed or MACed. It is not possible to use multiple signature or MAC in a JWS Compact Serialization and furthermore it is not allowed to use JWS Unprotected Headers. An unprotected header is a JSON object which includes the header element that is not integrity protected, which concludes that a protected header is a JSON object that is integrity protected by using MAC or digital signatures. A JWS Compact Serializations is represented as a concatenated string [cf. (Jones, Bradley, and N., 2015)].

```

1  {
2  BASE64URL(UTF8(JWS Protected Header)) '.'
3  BASE64URL(JWS Payload) '.'
4  BASE64URL(JWS Signature)
5  }
```

Listing 2.5: JWS Compact Serialization

The first element is called the JOSE header which contains all the information that advertises the public key corresponding to the private key that was used to sign the message. Elements of the header include the jku, jwk, kid, x5u, x5c, x5t and x5t#s256. The second element is the JWS Payload or the content to be signed, which does not have to be JSON. To construct the message the following approach is used ASCII(BASE64URL-ENCODE(UTF8(JOSE Header))) '.' BASE64URL-ENCODE(JWS Payload)). The last element is the JWS signature, which is computed over the message that was constructed beforehand, using the algorithm defined in the JOSE Header. These three key components together are called a JWS token. When using the JWE Compact Serialization, the output is called JWE token. Compared to the JWS token, which we saw above the JWS token consists of 5 different key components [cf. (ibid.), (Jones and Hildebrand, 2015)].

```

1  {
2  BASE64URL-ENCODE(UTF8(JWE Protected Header)) '.'
3  BASE64URL-ENCODE(JWE Encrypted Key) '.'
4  BASE64URL-ENCODE(JWE Initialization Vector) '.'
```

```
5  BASE64URL-ENCODE(JWE Ciphertext) '.'  
6  BASE64URL-ENCODE(JWE Authentication Tag)  
7  }
```

Listing 2.6: JWE Compact Serialization

Both digital signatures and MACs can be used to provide integrity checking. However, specification warns that there significant differences that have to be considered when designing a protocol. MACs only provide the origination of the identification under specific circumstances. It is normally assumed that the private key used for the signature is only known by a single entity. Although in the case of MAC keys all the entities that use it for integrity computation need to know the MAC key in order to validate the message. That means that with MAC validation one can tell if a message is generated from one of the entities that know the symmetric MAC key and not where the message originated [cf. (Jones, Bradley, and Sakimura, 2015)].

2.6 Single Sign-On Federation Systems

Application security is a complex task and developing a customized siloed identity solution can be expensive. A Stand-alone identity store can besides being expensive also causes information assurance and administrative problems for organizations [cf.(JerichoSystems, 2018)].

A federate authentication or identity federation says Boyed, 2012 is a system that is maintaining its accounts, for example, username and password databases, with the help of third-party service. Often big cooperate IT environments already use such solutions. Environment applications, for example, may trust an Active Directory server, an LDAP server or a SAML provider [cf. (Birrell and Schneider, 2013), Boyed, 2012].

As shown in (figure 2.4) an identity system usually consists of three parties. The user/-subscriber, service provider/resource provider, and the identity provider. Depending on the protocol which is used, different information passes between the three components at different times. While the user/subscriber communicates with the IdP and the RP over a browser the IDP and the RP can communicate over a front channel which works through redirects involving the subscriber or a back channel which is a direct connection not including the subscriber [cf. (Grassi, Richer, et al., 2017)].

The user/subscriber is usually associated with a real user, and its identity is represented by a set of attributes. Single user can be associated with multiple identities.

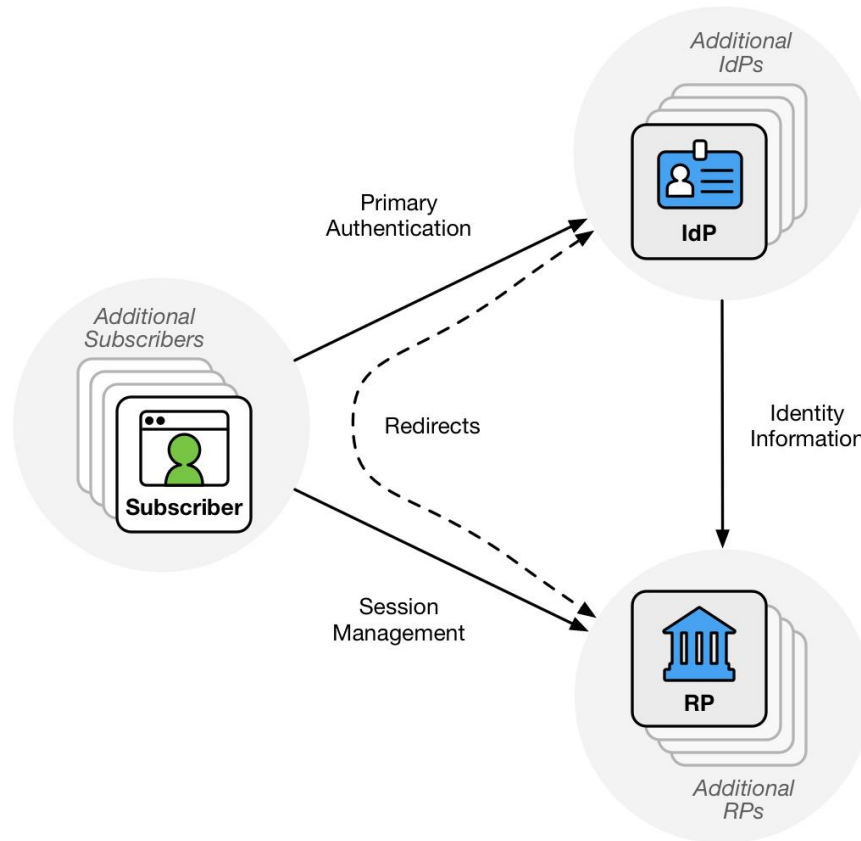


Figure 2.4: Federation

A service/resource provider is responsible for making an authorization decision based on authentication assertion and the attributes derived from it. Many of the service providers implement their identity management, but in federate systems, the identity management is outsourced to the identity provider. An identity provider can be either a stand-alone service or be a part of the service provider. The responsibility of the IdP is it to authenticate the user, issuing authentication assertions, manage identities whereas the IdP has the right to create, update, release and delete attributes associated with the identity [cf. (Birrell and Schneider, 2013)].

Grassi, Garcia, and L., 2017 claims that identity federation is preferred over some siloed identity solution that each serve a single agency or Relying Party (RPs). Furthermore *ibid.* lists specific benefits that come with using federated architectures, as can be examined before.

- Enhanced user experience. For example, an individual can be identity proofed once and reuse the issued credential at multiple RPs.
- Cost reduction to both the user (reduction in authenticators) and the agency (reduction in information technology infrastructure).

- Data minimization as agencies does not need to pay for collection, storage, disposal, and compliance activities related to storing personal information.
- Pseudonymous attribute assertions as agencies can request a minimized set of attributes, to include claims, to fulfill service delivery.
- Mission enablement as agencies can focus on the mission, rather than the business of identity management.

Essentially switching to a federated identity solution should help to reduce the management burden that comes from managing multiple accounts and can lead to potential points of failure. Furthermore users are giving control over there attributes' dissemination which leads to privacy violations and identity theft. Most of the existing identity federation solution focuses on individual system, each of which focuses on one of three general types of functionality - single sign-on, federated identity or anonymous credentials. Single sign-on system have the possibility to issue authentication assertion to multiple service providers. Examples for single-sign on are Passport, OpenID or Shibboleth. Federated identity systems are focused on managing multiple identities for a single user. Example for Federated identity are Project Liberty (<http://projectliberty.org>), Higgins (www.eclipse.org/higgins), PRIME (www.prime-project.eu), CardSpace, and Client-Side Federation. Anonymous credentials systems provide authentication assertions while not revealing the user's identity to a service provider. Examples include Idemix, U-Prove, and P-IMS [cf. (Birrell and Schneider, 2013), Boyed, 2012].

2.6.1 Singel Sign-On

The focus of this thesis is on mobile SSO solutions. Therefore only SSO solution will be discussed. The aim of SSO is to design an authentication system that serves the interests of the user as well as the interests of the service provider. Whereas the user prefers a simple process, the service provider requires a complicated authentication procedure. Ironically trying to make the authentication procedure more save often leads to weakening the whole system due to the user always finding new ways to bypass it. An example mentioned before is password fatigue. Another challenge that SSO is trying to tackle is that standard web authentication solutions that require the user to login with a password, only authenticate the user and are not capable of providing access control or revealing additional information about the user. Most SSO solutions, therefore, try to combine the authentication process and authorization [cf. (Procházka, Kouřil, and Matyska, 2010)].

The paper Taxonomy of Single Sign-On System Pashalidis and Mitchell, 2003 identifies four generic architectures for SSO systems. An SSO system has to authenticate a user to a SP. Because authentication also implies identification, SSO systems have to incorporate the lifecycle management of identifiers that can take various forms. The paper distinguishes between two main types of SSO systems. The first type is ‘pseudo-SSO’ and the second type is ‘true SSO’. Typical pseudo-SSO are providing automatic authentication for all SP specific authentication methods after the user initially authenticated with the pseudo-SSO component, which is called primary authentication. The responsibility of a pseudo-SSO service is to manage all identities. A user may have multiple SSO identities for a single SP, but in principle, one SSO identity corresponds to one SP. Compared to the pseudo-SSO system in a true-SSO system, the user has to initially authenticate with the Authentication Service Provider (ASP) that is required to have an established relationship with all SPs. The relationship between the ASP and the SP has to be trustworthy. A key functionality of the true-SSO service is that the only authentication that includes the user occurs between the user and the ASP. The SP will get notified of the authentication status, including information about the identity of the user, with so-called authentication assertions. The categorization of SSO architectures can be further distinguished by the location of the ASP/pseudo-SSO component. This component can be either local to the user platform or offered as a third-party service also called SSO-proxy. This further categorization leads *ibid.* to the four generic architectures mentioned above Local pseudo-SSO systems, Proxy-based pseudo-SSO systems, Local true SSO systems and Proxy-based true SSO systems [cf. (*ibid.*)].

When opting for a particular SSO architecture, one has to consider the strength and weaknesses of each system carefully. The paper, therefore, analyses the four generic architectures regarding Pseudonymity and Unlinkability, Anonymous Network Access, Support for User Mobility, Deployment Costs, Maintenance Costs, Running Cost and Trust Relationships. Pseudonymity and Unlinkability refer to the fact that the user provides sensible information that needs to be protected and it should not be possible to correlate distinct identities of the same user and personal information, and potential properties should not be linked to the user. The unlinkability cannot be guaranteed for pseudo-SSO because the identities for the SSO are SP specific. To improve unlinkability *ibid.* suggest to use an ‘anonymizing proxy’, for local SSO system additionally services are needed for proxy-based SSP it can be integrated. User mobility is supported for proxy-based SSO, for locale SSO there needs to be further services in place. The deployment cost is lower for pseudo-SSO systems then for true-SSO systems. However, the maintenance cost is higher because if any SPs change the whole logic of the pseudo-SSO system has to change. The running cost of pseudo-SSO is likely to be

lower than for true-SSO systems. For the pseudo-SSO systems, the trust relationship between users and SP may be dynamically changing depending on the implementation, for true-SSO the trust relationship is established between ASP and SPs and is always consistent. Generally speaking are pseudo-SSO systems more suitable for a closed system where identity management is just for managing the life cycle of remaining credentials. For an open system maintaining credentials is not enough. Appropriate privacy protection services and privacy-aware Identity Management schemes should be therefore integrated with true SSO schemes [cf. (Pashalidis and Mitchell, 2003)].

Therefore two very popular assertion technologies are discussed: Shibboleth (SAML) and OpenID Connect. Those technologies are not all possible single sign-on assertion technologies. However, they present the most commonly used in federated identity systems. According to (Lynch, 2011) two SSO solutions gained broad acceptance. On the one hand, SAML-based federations using SOAP, focusing on large enterprises also including governments and educational networks. On the other hand, the Web Authorization Protocol was introduced which is a combination of the Protocols OpenID and OAuth. SAML federations have been customized to address the security concerns of those institutions that typically have a large user base, significantly protected resources, complex authorization patterns and data and services spread across multiple domains. However, in a Web 2.0 world, the SAML solutions were seen as too rigid and too severe to maintain; a lightweight SSO was needed, therefore the Web Authorization Protocol was designed. The approach of this protocol is taking advantage of the lightweight RESTful APIs which are reusing the existing HTTP architecture features and the JavaScript Object Notation(JSON) [cf. (ibid.)].

SAML One of the well-known solutions based on Security Assertion Markup Language version 2 (SAML2) is Shibboleth. Shibboleth is one of the leading middlewares for building identity federations in a higher education sphere. To offer authentication, authorization and attribute assertion between entities. Procházka, Kouřil, and Matyska, 2010 identifies the following entities defined by Shibboleth are Identity Provider (IdP), Service Provider (SP), Discovery Service, Metadata Operator and Federation Operator.

The discovery service is used to find the users organization IdP. The IdP defines an attribute release policy and releases different sets of the user's attributes to different SPs. Users are only able to agree or disagree with the whole set of attributes because the decision comes from the IdP. When the user tries to log on, to a service of a Service Provider, he gets redirected to a page where he can choose and IdP previously found by the Discovery Service. If an SP wants to provide its service to multiple federa-

tions it has to negotiate policy and technical detail with each federation operator. The federation operator manages the federation policies and introduces SPs and IdPs. Furthermore, the federations operator has to maintain and manage the information about all entities in a federation which is contained in the Metadata. A problem with this architecture is that the SP has to keep track of changes of the technical specification of various federation operators to maintain the configuration for each federation operator. A solution would be a significant federation registration, but this is indeed not possible because of technical and administrative severity and political will. This solution is also somewhat misleading for users since they have to maintain multiple credentials, select from multiple identifiers and so on [cf.Procházka, Kouřil, and Matyska, 2010].

According to *ibid.* Shibboleth is too restrictive, a solution with a centrally managed point of IdPs and SPs is preferred. Also, users should not have to deal with redundant accounts.

OAuth and OpenID Connect The second solution that is introduced here is OAuth 2.0 with OpenID Connect. OAuth 2.0 is a protocol that is used for access control. OAuth2.0 is the newest version of OAuth. Compared to the previous version OAuth1.0a, HTTPS is used for all request, and the complicated signature process of tokens was replaced. Furthermore, complexity was reduced, and the usage is much simpler than in the first version. The new version OAuth 2.0 is not compatible with older versions [cf. (LeBlanc, n.d.)].

The protocol adds an authorization layer – separating the Client from the Resource Owner. The Client is not bound to any particular implementation characteristics and can make requests to protected resources on behalf of the resource owner. The OAuth 2.0 specification distinguishes between two Client Types, Confidential Clients, and Public Clients. Whereas Confidential Clients are capable of maintaining the confidentiality and Public Clients that are incapable of maintaining confidentiality [cf. (cf.Hardt, n.d., p.6-14)].

The Resource Owner is a role according to (Sakimura, Bradley, Jones, Mederios, et al., n.d., p.6) can grant access to a protected resource also referred to as End-User, if the resource owner is a person. Furthermore, scopes are used to specify to which resources the resource owner wants to grant access. Requests that which are sent to an authorization endpoint include scopes that can be mandatory or optional parameters. Declaring the scopes is up to the provider. An access token is used to gain access instead of the resource owner's credentials.

Access Tokens are issued by an Authorization Server and can be used by the Client to gain access to protected resources hosted by the resource server. The Authorization Server is responsible for issuing the access token and may be the same as the Resource Server. In literature, in fact, different terms in literature do are used which describe what an identity server does. Among these are, some of them are Security Token Service, Identity Provider, Authorization Server and IP-STs. OAuth 2.0 uses a token service, which centralizes this logic and reduces complexity for the Client and the APIs [cf. (Sakimura, Bradley, Jones, Mederios, et al., n.d., p.6), (Brock and Dominick, n.d.), (Boyd, 2012)]

A typical request of a Client to access a resource on the Resource Server includes some requests. In the end, the Client should be able to access the protected resource. The process is shown in 2.5.

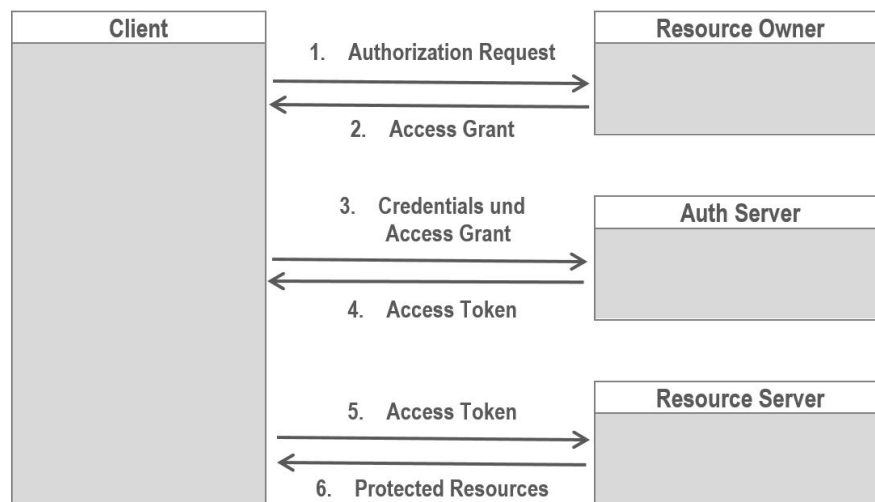


Figure 2.5: OAuth Authorization Process (LeBlanc, n.d., p.353)

In the first two steps, the Client redirects the User to the Resource Owner, to give the Client permission to access the protected resources. The User is then redirected to the callback location which is included in the original request and adds a verification code which confirms that the Client is entitled to access the requested resource. After the redirection to the callback location, the Client sends a request with the verification code to the Authorization Server. If the request is a success, the Authorization Server replies in step 4 with an access token and eventually a refresh token. With the received access token the Client can now make signed requests to the resource server and receive protected resources as shown in step 5 and 6 [cf. (LeBlanc, n.d., p. 353)]

OpenID Connect and OAuth 2.0 seem very similar, in fact, OpenID Connect is a framework build on top of OAuth 2.0. Together they focus on Authentication and Access

Control in a way that is suitable for modern applications. OpenID can verify the identity of an End-User and obtain basic profile information about the user. It uses Claims to communicate information to the End-User [cf. (Sakimura, Bradley, Jones, Mederios, et al., n.d.)]

OpenID Connect performs authentication and determines if the user is already logged on or to log on the user. The result is an authentication token which is returned to the user. A precondition of OpenID Connect is that the client, as well as the user, have to trust the IdP. The functions of the IdP are the same as in OAuth. The reason for that is that the newest version of OpenID is implemented on top of OAuth and extends the authentication process of OAuth [cf. (ibid.), (Boyd, 2012, p.51)]

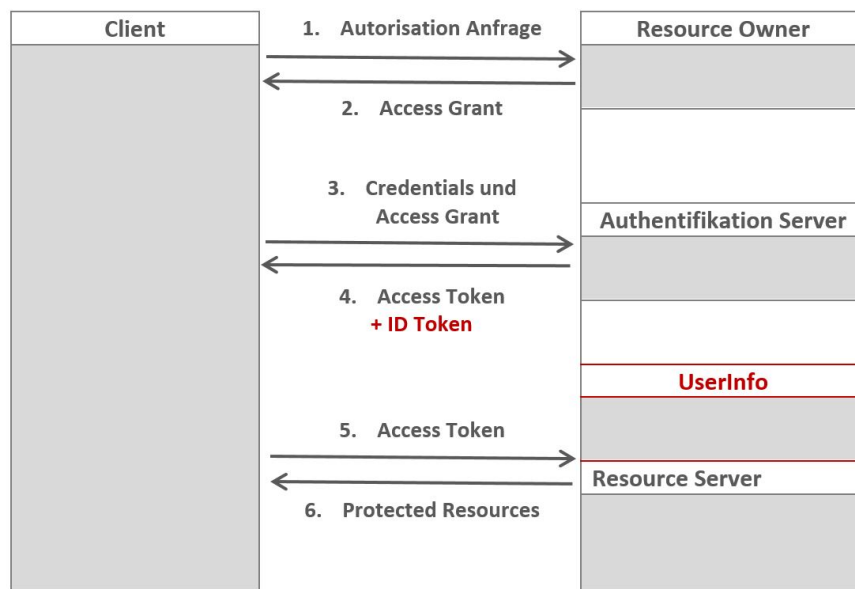


Figure 2.6: OAuth 2.0 and OpenID Connect Lodderstedt, n.d.

In figure 2.6 OAuth 2.0 and OpenID Connect Lodderstedt, n.d. the added Element of the OpenID Connect standard is marked with red. In order to implement the OpenID Connect Standard, the Client has to request the scope 'openid'. After the request, the progress is similar to the transitional OAuth authentication process, but when it comes to return of the access token, a additional ID Token is returned. This ID Token holds information about the user and the authentication. The only purpose of the ID Token is to log in the client. The only thin left after this is for the client to verify the ID Token [cf. ibid.].

The ID Token is specified by Sakimura, Bradley, Jones, Mederios, et al., n.d. as a JWT compared to OAuth where the type of token is irrelevant. The token is signed and has some particular claims. Further individual claims could also be added to the ID

token. The ID token has claims that are required for the authentication process. Also, standard claims can be added which are predefined by OpenID Connect. Those claims could also be requested from UserInfo Endpoint shown as an additional endpoint in the figure 2.6 OAuth 2.0 and OpenID Connect Lodderstedt, n.d. The user info endpoint offers an API where additional user info can be requested [cf. (Sakimura, Bradley, Jones, Mederios, et al., n.d.)].

Lodderstedt, n.d. says that OpenID Connect is a contemporary advancement from protocols like SAML. The protocol considers the ongoing development of web services and mobile applications. Furthermore, the implementation of the protocol is quite easy and uses little HTTP requests with minimal cryptographic overhead to accomplish a complete login process [cf. (ibid.)].

Sakimura, Bradley, Jones, Mederios, et al., n.d. defines three different way authentication can flow:

1. **Authorization Code Flow** - The Authorization Code Flow returns an Authentication Code which can be used to be exchanged for an `id_token` or an `access_token`. The Authorization Code is used for Clients that can maintain a secret securely between themselves and the Authorization Server. Typically this approach is used for server-to-server communication when no interactive user is present. In this thesis, the focus is on user interaction [cf. (ibid., p.10)]

To use the Authorization Code Flow according to ibid. the the following request_type indicates a Authorization Code Flow:

- `code`: The response includes an Authorization Code.

2. **Implicit Code Flow** - In the Implicit Code Flow the access token and the ID id token are directly returned to the Client. This behavior may expose information to the End-User or anyone who has access to the End-User's Agent. Tokens are only returned from the Token Endpoint; the Authorization Endpoints is not used. Unlike the Authorization Code Flow where the separate request is used for authorization and authentication, here the Client will receive the access token as a result of the authentication which also means that there is no refresh token. This flow is used for Clients who are implemented in a browser using scripting language [cf. (ibid., p.20), (Hardt, n.d.)]

According to Sakimura, Bradley, Jones, Mederios, et al., n.d., the following request_types indicate an Implicit Code Flow:

- `id_token`: The response must include the parameter `id_token`. The response

does not include an Authorization Code, Access Token, or Access Token Type.

- `id_token` token: The response includes an Access Token, an Access Token Type and an `id_token`.

3. **Hybrid Code Flow** - In the hybrid code flow, tokens are returned from the Authorization Endpoint, and others are returned from the Token Endpoint. The Token Server will return not only the `id_token` but also the code. The Client then has to use the code in order to gain the access token through a back channel call which means there is an additional round trip compared to the Implicit Code Flow. Using the code to receive the access token should minimize the risk of exposing the access token [cf. (Sakimura, Bradley, Jones, Mederios, et al., n.d.)]. To use the Hybrid Code Flow according to de *ibid.* put forward that the following `request_types` indicate a Hybrid Code Flow:

- `code id_token`: The response includes an Authorization Code and an `id_token`.
- `code id_token token`: The response includes an Authorization Code, an Access Token, an Access Token Type and an `id_token`.

Both OpenID Connect and SAML SSO solution involve different layers of communication and exchange credentials using HTTP redirection and Javascript which leads to vulnerabilities. Vulnerabilities include Cross-Site Request Forgery and Cross Site Scripting. The authentication process for SSO solution includes redirects which can be exploited by attackers. As the SP redirects the User to the IdP, an attacker could intervene and send the user to a fake IdP. If the user does not recognize to swap from the real IdP to the fake IDP, the attacker ends up with the user's credentials. This problem is called a malicious IdP, also known as "phishing" and a very well-known attack against SSO. Another problem that a federation single sign-on system could be facing is a malicious RP or SP. After a User successfully authenticates on the IdP site, he is redirected back to the SP with a link. An attacker obtains a link with methods like sniffing and uses the link to get logged into the SP as the User [cf. (Xu, n.d.)].

OpenID Connect and SAML both provide SSO solutions, however there are a view differences between the two protocols. First in SAM a SP and in OpenID the RP redirects the user to the IdP. The assertions distinguish themselves by the markup language which is used. SAMLs uses a signed XML document and OpenID uses a signed JSON document. The JSON format makes tokens easier to parse with Javascript. Furthermore OpenID Connect was designed to work with the web while SAML was readjusted to work on top of the web [cf. (Schwartz, n.d.), (KeyCloack, n.d.)].

Schwartz, n.d. suggest to use OpenID Connect for mobile applications, API's and any new applications in general. SAML is just suggested for applications that already use SAML. However KeyCloack, n.d. expresses that choosing between these SSO protocol is not a straight forward. Although they recommend the use of OpenID Connect, they see notice the gradually development of OpenID Connect and how more and more features are implemented that SAML had for years. Therefore some people tend to pick SAML over OIDC based on the perception that it is more mature.

Practical Part

The practical part of this work is made up of three parts: the use case, a risk assessment and an example solution based on what was learned from the risk assessment. In the first part a use case is described. The use case tries to picture a typical scenario that requires thoughtful consideration of authentication and authorization technologies depending on the requirements of the use case. Based on the uses case a small risk assessment is done. This risk assessment should help to choose an appropriate level of assurance for identity proofing, authentication and federation. Based on this risk assessment a small application is implemented. The solution represents a federate single-sign on solution which uses modern open source authentication and authorization protocols. This procedure should help developers to choose appropriate authentication and authorization methods for a particular use case. The goal is to balance usability and security.

3.1 Use Case

This use case is entirely fictional but allows the reader to get a better understanding of the circumstances a that led to the design of a federated authentication solution.

The use case features a medium to large company with up to 1000 employees. The mission of the company is to provide a network and analyzing toolset which allows the customer of the product suite to improve security within his network and keep an overview of potential security risks. Previously the customers received monthly reports about their current state of the network. Each of the products and tools resulted in a separate report which was sent via E-Mail. To modernize the approach, the reports

should be replaced by a modern single-page application that could be accessed by customers and by employees for administrative reasons. In this example, we call the solution 'Security Assessment Portal.' The Security Assessment Portal should give the customers an overview of current products and the performance of the network an example of the suit could be E-Mail-Filtering. The example will be focused on an E-Mail-Filtering-Report and the data which is exposed via the report. It is very important to have a good overview of the data that is used within the application in order to establish appropriate security controls. The Email-Filtering-Report will display a chart per domain. The chart includes data about the amount of e-mails which were blocked, received or carried a virus.

The company already has a particular set of internal applications that are used by the employees within the company network. The company internally uses active directory for authorization on local machines. All applications until now are accessible within the companies network and use windows authentication. The application should be accessible by employees as well as customers whereas customers should not receive access to the company network. The data of the customers are sensitive and therefore worth protecting. However it should be kept in mind that because of the sensitive data, certain customer do not want to authenticate with an external provider. The application should be hosted within the company a solution for customers to access the application from outside is needed. The company needs an authentication solution that meets all the outlined requirements while balancing usability and security.

3.2 Risk Assessment

Risk Assessment is one of the essential elements when it comes to managing risks of an organization. The aim of risk assessment is it to identify, estimate, and prioritize risk to operations, assets, individuals, other organizations from the operations and use of the information system. The risks assessment should help to make decisions on how to respond to certain risk. The steps to a risk assessment are identifying potential threats, internal and external vulnerabilities, the impact to organizations given the potential for threats exploiting vulnerabilities and the likelihood of that harm to occur. There are three tiers according to (NIST (National Institute of Technology), 2012, p.1) in risk management:

- Tier 1 - organizational level
- Tier 2 - mission/business process level

- Tier 3 - information system level

The first two Tiers are focusing on risks related to organizational governance and management activities, mission/business processes, enterprise architecture or the funding of information security programs. The third Tier focuses more on how to implement a risk management framework successfully [cf. (NIST (National Institute of Technology), 2012, p.1)].

The result of the risk assessment should state which assurance levels are appropriate. Identity proofing assurance level describes the robustness of the process to determine the identity of an individual and should help to avoid identity proofing errors. To determine the robustness of the authentication process and the binding of an authenticator and a specific individual's identifier the authentication assurance level is used. Furthermore choosing an appropriate authentication assurance level should help to avoid authentication errors. The last one of the assurance level is the federated assurance level which is optional since not all identity systems need a federated identity solution. The federated assurance level determines the robustness of the assertion protocol the federation uses to communicate authentication and attribute information and should help to avoid federation errors. All of the assurance levels are described in more detail in the sections 2.2 Identity Proofing, 2.3 Authentication and 2.4 Assertion [cf. (Grassi, Garcia, and L., 2017, p.19)].

To determine assurance levels the potential risk and the measures to minimize the impact of this risk are identified. Two factors are crucial for this task. The first factor is the potential harm or impact, and the second the likelihood of such harm or impact. Bolton, n.d., pp.3 splits harm and impact into these categories:

- Inconvenience, distress, or damage to standing or reputation
- Financial loss or agency liability
- Harm to agency programs or public interests
- Unauthorized release of sensitive information
- Personal safety
- Civil or criminal violations

Assurance levels are determined by assessing the potential impact of these categories. Standards and Technology)), n.d. defines three levels of potential impact concerning security objectives confidentiality, integrity, and availability. Those levels of potential impacts can affect either the organization or individuals should there be a breach of

security. The levels of impact defined by Standards and Technology)), n.d. are:

- Low
- Moderate
- High

If the level is low the loss of confidentiality, integrity or availability has a limited effect. This can mean for example minor damage to organizational assets, short-term inconvenience, short-term distress, short-term embarrassment, limited reveal of personal or sensitive information to unauthorized parties with minor impact, minor financial loss, risk of civil or criminal violation which would not ordinary be subject to enforcement efforts, minor harm to individuals or the capability of the company to fulfill their mission is degraded. If the level of impact is moderate the effects of loss of confidentiality, integrity or availability are serious. Impacts can be significant damage to organizational assets, significant financial loss, serious short-term or limited long-term inconvenience, serious short-term or limited long-term distress, serious short-term or limited long-term damage to standing reputation, release of personal or sensitive information to unauthorized parties with moderate impact, risk of civil or criminal violations which may be subject to enforcement efforts, significant harm to individuals or significant degradation of mission fulfillment. The last level of potential impact is high, meaning that the effects can be severe or catastrophic. This means for example major damage to organizational assets, major financial loss, severe or serious long-term inconvenience, severe or serious long-term distress, severe or serious long-term damage to standing reputation, release of personal or sensitive information to unauthorized parties with high impact, risk of civil or criminal violation with special importance to enforcement programs, harm to individuals involving loss of life or serious life-threatening injuries and loss of capability to fulfill the mission [cf. (ibid., pp.6), (Grassi, Garcia, and L., 2017, pp.21)].

To determine the minimum LOA needed the results of the risk assessment. The risk assessment impact profile can then be compared to the impact profiles associated with each assurance level. The table 3.1 'Maximum Potential Impacts for each Assurance Level' can help to determine the required assurance level by finding the lowest level whose impact profile meets or exceeds the potential impact for every category analyzed in the risk assessment [cf. (ibid., p.25)].

When analyzing the risk, it should be considered that there could be more than one error and multiple parties could be involved in the process. Furthermore, the potential impacts description often include relative terms like 'minor' and 'serious' which

Impact Categories	Assurance Level		
	1	2	3
Inconvenience, distress or damage to standing or reputation	Low	Mod	High
Financial loss or agency liability	Low	Mod	High
Harm to agency programs or public intrests	N/A	Low/Mod	High
Unauthorized release of sensitive information	N/A	Low/Mod	High
Personal safty	N/A	Low	Mod/High
Civil or criminal violation	N/A	Low/Mod	High

Table 3.1: Maximum Potential Impacts for Each Assurance Level (Grassi, Garcia, and L., 2017, p.25)

meaning will depend on the context. Over time and with experience the meaning of these relative terms becomes more definite [cf. (Grassi, Garcia, and L., 2017, p.26)].

One of the most useful documents is NIST's 'Guide for Conducting Security Risk assessment'. The guide follows activities related to NIST'S guide of 'Risk Management Framework' which can be either applied to new or legacy information systems. Typically a risk assessment is a very complex task that takes much time many external sources to be representative, like for example expert opinions. If put together correctly one should end up with a Risk Management Framework (RMF). An RMF provides a process that integrates security and risk management activities into the system development life cycle. The system can be applied to both new and legacy systems. Standards and Technology), n.d. defines 6 Steps in this RMF. The steps include the categorization of the information system, selection of baseline security controls, implementation of security controls, assessment of the security controls, authorize information system operation based on the determination of risk and monitoring security controls. Many industrial standard risk assessment methods across a wide array of fields and industries are based on these guides. In this practical part, an initial risk assessment is done which should provide a general feeling on how to do a risk assessment. The guide to the success of a real-life risk assessment is documentation, review, and improvement. However, since a full RMF is out of the scope of a scaled down version that is specific to digital identity risk management is conducted (ibid.).

To prepare for a risk assessment, it helps to identify the purpose, scope, assumptions, and constraints beforehand. The purpose of this risk assessment is to make

authorization-related decisions and conducting an initial assessment to identify potential threats, internal and external vulnerabilities which impact the organizations. The scope addresses the 3 Tier - information system level with a focal point on the risk assessment of a single sign-on federation system. Furthermore, the scope is defined by the result expected from the risk assessment. In this risk assessment, the result should be an authentication and authorization solution for a specific use case. The assessment result should usually be reevaluated after the initial draft. [cf. (NIST (National Institute of Technology), 2012, pp.24)].

Before starting with the risk assessment a risk model has to be chosen for the risk assessment. The model can be translated into risk factors which then can be assessed; these risk factors consist of threat, vulnerability, impact, likelihood and predisposing conditions. A threat is a circumstance with the potential to impact the organization. Threat events are caused by threat sources. Threat sources that should be considered in the model can address broad threat sources or particular threat sources. Potential threat sources can be adversarial like Insider, Outsider, Trusted Insider Privileged Insider, Customer, Competitor. A threat source can also be accidental like User, Privileged User/Administrator or structural like IT-Equipment (Storage, Communication, Processing), Environmental (Temperature/Humidity, Power Supply) or Natural (Fire, Bombing, Earthquake, Sunspots). These potential sources can then cause threat events which can be expressed very general or can also be very specific. Which threats are considered depend highly on the company. A company might choose to only consider previously observed events or all possible events. Examples of potential threat sources are Cause integrity loss by injecting false but believable data into organizational information systems, Obtain unauthorized access, Obtain sensitive data/information from publicly accessible information systems, Cause disclosure of critical and/or sensitive information by authorized users, Conduct externally-based session hijacking, Conduct simple Denial of Service (DoS) attack, Craft phishing attacks and so on. The likelihood is a weighted risk factor based on the probability that a given threat is capable of exploiting a given vulnerability. A vulnerability is an existing weakness in an information system, system security procedures, internal controls, or implementation that could be exploited by a threat source. Most vulnerabilities are caused by security controls that are not implemented or not implemented correctly and still retain some weakness. Some recommended security controls are described in 'Recommended Security Controls for Federal Information Systems and Organizations'. The implementation of appropriate security controls is an important task that can have a major impact on the operations and assets of a company. Security controls are used to protect the confidentiality integrity and availability of a system and its information. Examples are Identifier

Management, Authenticator Management or Authenticator Feedback. Closely related to vulnerabilities is a predisposed condition which is a condition within a company which affects the likelihood that threat events one initiated result in adverse impact on the organization like the involvement of PII. The consequences that a successfully exploited vulnerability by a threat source has is then described by the impact [cf. (NIST (National Institute of Technology), 2012, pp17, pp35, pp70), (Grassi, J. Fenton, et al., 2014)].

Last but not least before stating a risk assessment based on a risk model an analytic approach and an assessment approach should be considered. The assessment approach can be quantitative, qualitative or semi-quantitative each of the factors including three assessment scales with different corresponding representations. A quantitative assessment is based on the use of numbers whereas the qualitative assessment typically uses nonnumerical categories or levels like very low, low, moderate, high, very high. Finally, semi-quantitative assessment is a combination of a quantitative and a qualitative assessment using bins, scales or representative numbers which meaning are not maintained in other contexts. For low impact information systems, the qualitative values are used while for moderate-and high-impact systems; the most granular semi-quantitative values are used. The analysis approach is either threat-oriented, asset/impact-oriented or vulnerability-oriented. The analysis approach lets one choose the starting point of the risk assessment. The risk assessment starting point can be either based on existing vulnerabilities or assets in the company or possible threats [cf. (NIST (National Institute of Technology), 2012, pp17)].

Based on this knowledge a view examples considering the use case above where conducted. Based on the descriptions above and on a example from Hudson, n.d. the following steps were followed Identify Threat, Identify Vulnerability, Current Controls, Likelihood of Impact, Effect of Impact and Risk Determination. Since it is an initial risk assessment, there are no Current Controls. Therefore, this step is left out. The Likelihood of Impact can be assigned a value from low to high whereas high means it is very likely that a vulnerability is exploited by a threat. The lowest value of Likelihood of Impact is 0.1, and the highest is 1. The Effect of the Impact is assigned a value between 0 to 100. A low Effect of Impact means that the consequences are low and high Effect of Impact means that the consequences are severe. To determine to the overall risk of a threat, the Likelihood is multiplied with the Impact (Likelihood x Impact) resulting in the risk levels:

- Low = 0-33
- Medium = 34-66

- High = 67-100

Since this analysis is about identity proofing, authentication and federation error a few threats were chosen to be analyzed with the risk assessment to be analyzed. It should be noted that this does not represent a complete risk assessment since there are more factors to be considered. The risk analyses see outsiders who want to harm the company and users as potential threat sources.

Identity Proofing Risk 1

1. Technical Threat: An attacker successfully proofs as someone else
2. Vulnerability: Phishing over unencrypted network communication
3. Likelihood: 0.5
4. Impact: 80 (Inconvenience, distress)
5. **Risk Determination:** $0.5 \times 80 = 40$ (Medium Risk)

Identity Proofing Risk 2

1. Technical Threat: Collecting and securely storing more information about a person that is required to successfully provide the digital service
2. Vulnerability: Identity Provider is collecting more information than needed from the user on login. Users might not trust the application or not use it
3. Likelihood: 0.8
4. Impact: 30 (Unauthorized release of sensitive information)
5. **Risk Determination :** $0.8 \times 30 = 24$ (Low Risk)

Authentication Risk 1

1. Technical Threat: False claimant using a credential that is not rightfully theirs
2. Vulnerability: User keeps credentials at an insecure place
3. Likelihood: 0.9
4. Impact: 60 (Inconvenience, distress and Unauthorized release of sensitive information)
5. **Risk Determination:** $0.9 \times 70 = 64$ (High Risk)

Authentication Risk 2

1. Technical Threat: Account is compromised and user is using same identifier and authenticator for other accounts
2. Vulnerability: User uses same credentials for multiply accounts
3. Likelihood: 0.8
4. Impact: 70 (Inconvenience, distress and Unauthorized release of sensitive information)
5. **Risk Determination:** $0.8 \times 70 = 56$ (Medium Risk)

Federation Risk 1

1. Technical Threat: An identity assertion is compromised
2. Vulnerability: Transaction involving third party not over protected channel
3. Likelihood: 0.6
4. Impact: 40 (Inconvenience, distress)
5. **Risk Determination:** $0.6 \times 40 = 24$ (Low Risk)

Federation Risk 2

1. Technical Threat: Identity Server is unavailable
2. Vulnerability: Environmental influences
3. Likelihood: 0.1
4. Impact: 100 (Inconvenience, distress and Financial loss)
5. **Risk Determination:** $0.1 \times 100 = 10$ (Low Risk)

An initial risk assessment can take a long time but once conducted the following risk assessments will be much quicker. Modern digital services often combine identity proofing, authentication and federation requirements in one single bundle. It is better to look at each of this components separately to delivery the best identity service. The outcome of the separate component can then be compared to 3.1 Maximum Potential Impacts on Each Assurance Level and which assurance Level is associated with the risk outcome. Therefore the highest risk is taken and associated with the appropriate assurance level. After the initial risk assessment with just a view threats that were

analyzed the associated risk level for identity proofing would be 2, for authentication risk, it would be 2, and for federated risk, the assurance level would be 1 [cf. (Grassi, Garcia, and L., 2017), (Standards and Technology), n.d.), (Hudson, n.d.)].

To make it easier to choose an initial assurance level the 'Digital Identity Guidelines' form Grassi, Garcia, and L., 2017 provide an additional assessment on how to choose appropriate assurance level. Therefore three flowcharts are provided that need to be followed and then point to an appropriate assurance level. The flow through the cart is represented with the color red. The first flow chart is 3.1 Identity Assurance Flow Chart. Choosing a Identity Assurance Level however does not mean that the identity proofing has to be done by the party who does the assessment - it can also be federate.

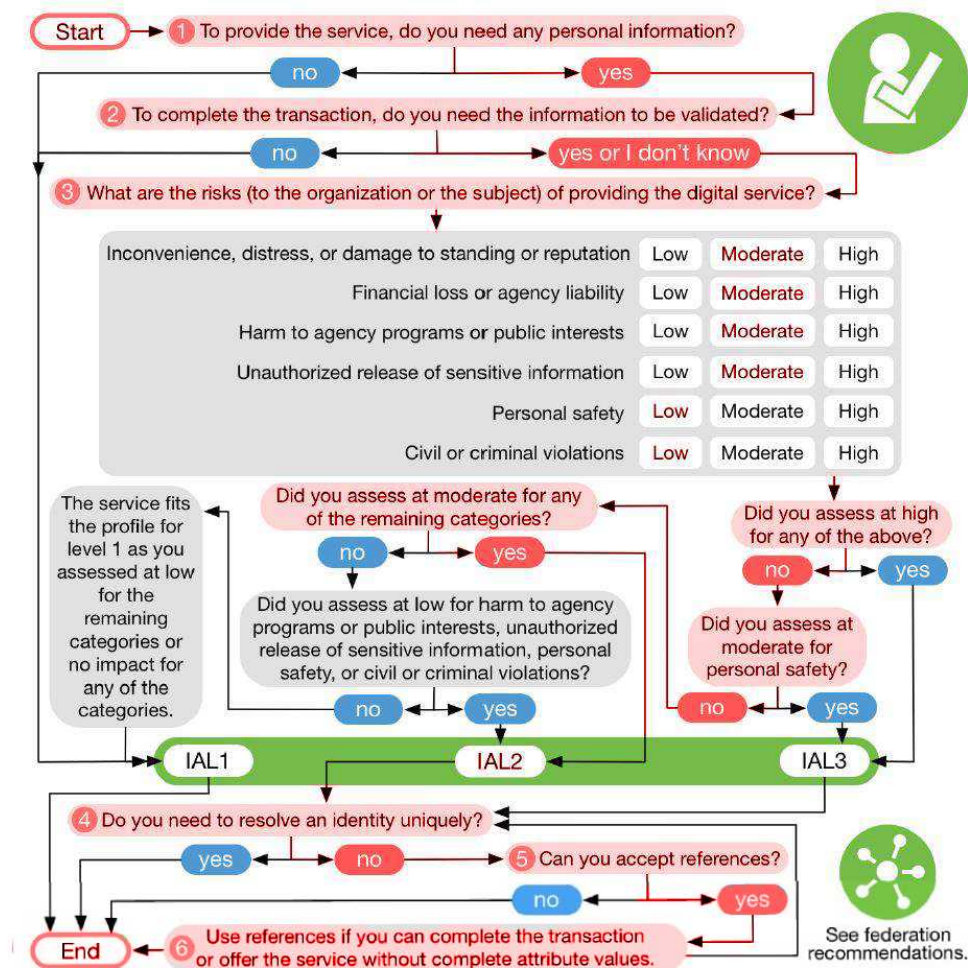


Figure 3.1: Identity Proofing Assurance Flow Chart (Grassi, Garcia, and L., 2017, p 27)

In 3.1 Identity Proofing Assurance Flow Chart the first question is if PII is needed to provide the service. In our use, probably sensitive company information is provided therefor yes personal information is needed. Some of the attributes that are provided

have to be validated and can not be self-asserted attributes only. The next step is about potential impacts of identity proofing. The two risk that is considered here are the most primary identity proofing failures from the view of the user and the company: accepting a falsified identity as true and collecting more information as needed. Question 5 focuses on whether the service should be able to access full attribute values. That does not mean that all attributes have to be delivered in claims, but it should be considered. If yes was picked at the question the service is an excellent candidate for a federated infrastructure [cf. (Grassi, Garcia, and L., 2017, pp28)].

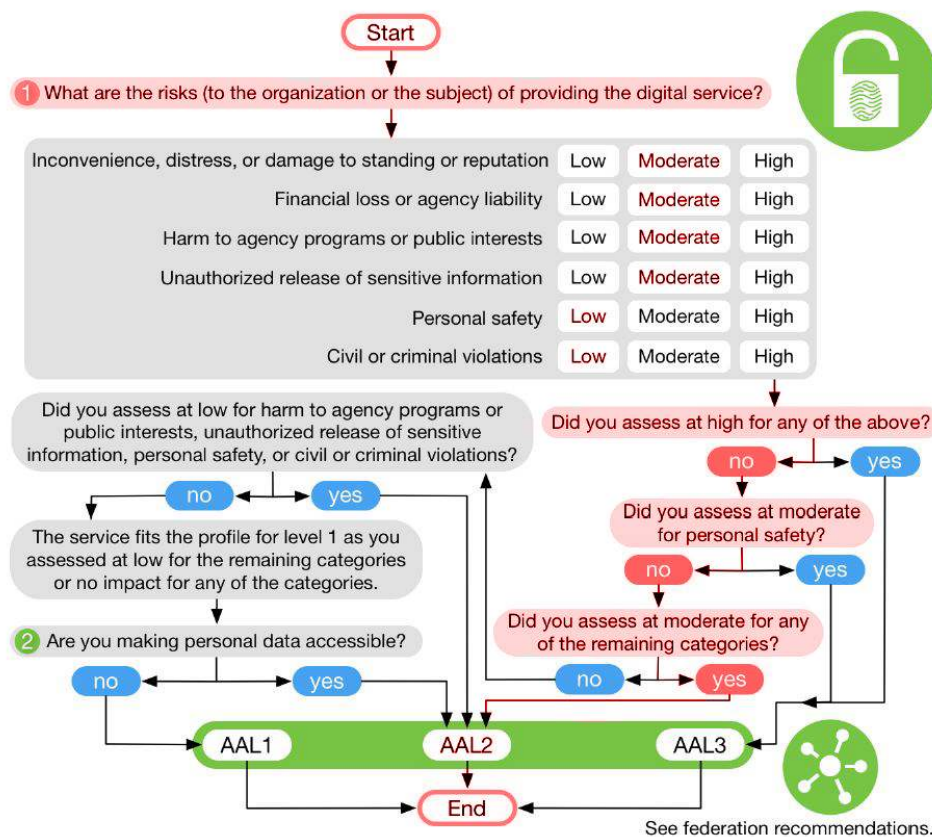


Figure 3.2: Authentication Assurance Flow Chart (Grassi, Garcia, and L., 2017, p 30)

The next flowchart is 3.1 Authentication Assurance Flow Chart which should help choose a company deciding on the authenticators necessary for the service. First, the risks of letting an unauthorized user access information from the perspective of the organization and the user are considered. In this use case company, sensitive information of the customer are endangered an e-mail filtering report however does not have devastating impacts on the customers business. Therefore the assessment ends with the AAL2 [cf. (ibid., pp30)].

Since it was evaluated in the 3.1 Identity Proofing Flow Chart that the service is rec-

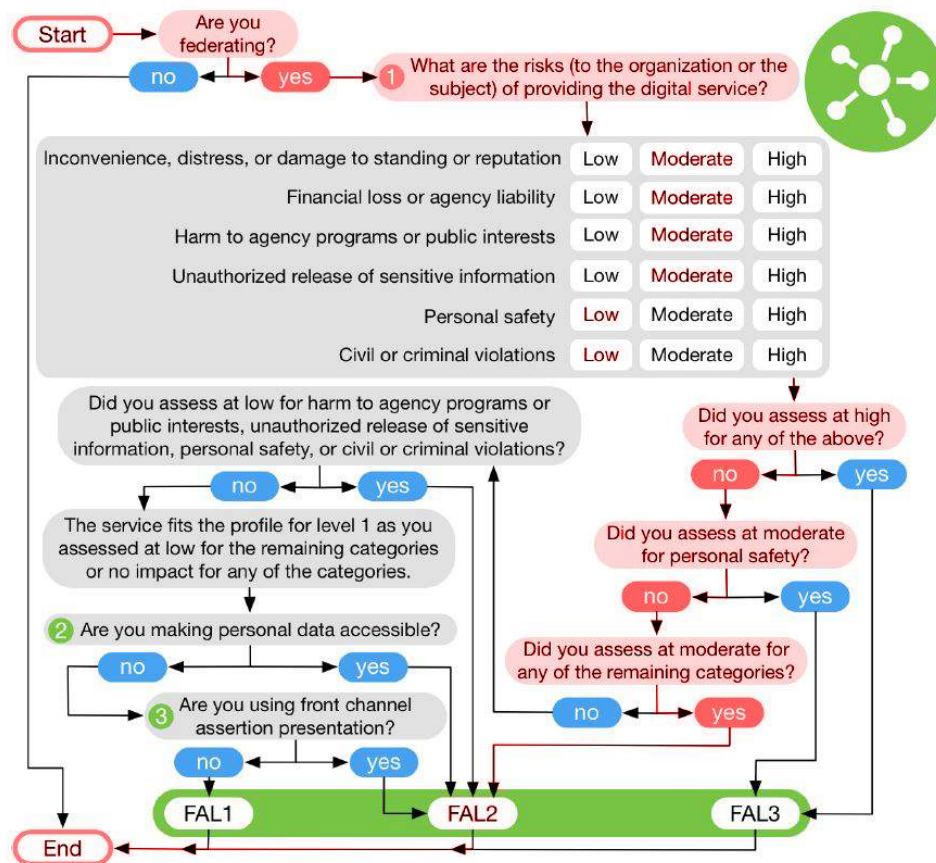


Figure 3.3: Federation Assurance Flow Chart (Grassi, Garcia, and L., 2017, p 32)

ommended for a federated solution the last flowchart is the 3.3 Federated Assurance Flow Chart. The first thing that is considered is the impacts of an unauthorized user compromising an assertion from the organization and the subscriber view. For example assertion replay to impersonate a valid user or leakage of assertion information through the browser. This lets us end up with assurance level FAL2 [cf. (Grassi, Garcia, and L., 2017, pp32)].

This initial assertion should give a general direction in which security controls should be in place passed on the different LOA. The risk assessment helps to balance out security and usability, to give the user the best experience. After the first realization of the project, the risk assessment should be done again and refined including the current security controls in place.

3.3 Solution

The Sakimura, Bradley, Jones, Mederios, et al., n.d. explains that modern applications have different requirements than their predecessor due to new distributed architectures that allow enterprises to be more flexible. Cloud or Microservice architectures require different interactions between applications as the 3.5 below show the most common interactions for modern applications.

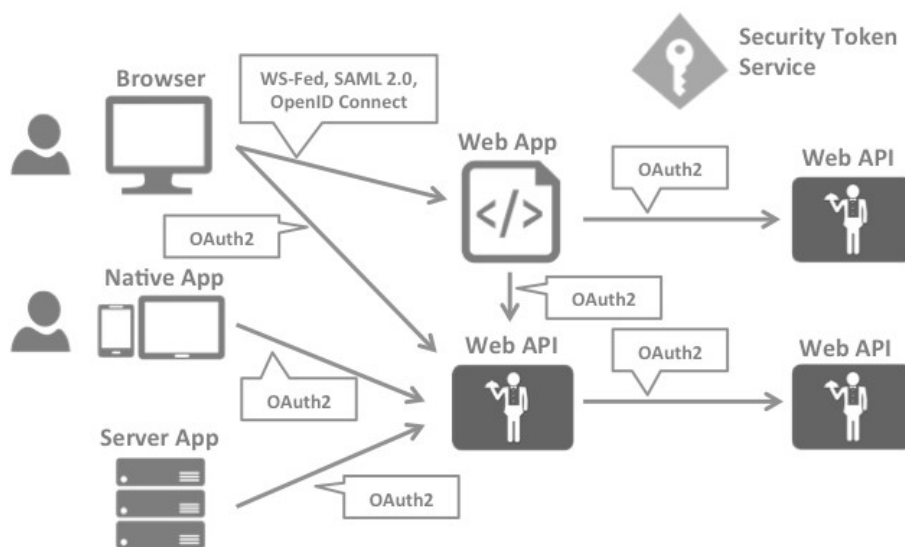


Figure 3.5: Architecture IdentityServer4 (Brock and Dominick, n.d.)

For example, a browser might call a Web App, and a Web App calls a Web API or perhaps a Native App calls a Web API, which is calling another Web API. Each application has to implement security functions to maintain a secure flow throughout these interactions. Implementing this security features for each involved application leads to a lot of duplicated code and inconsistencies. A different approach to implement security throughout these flows is using a token service. A token service brings the benefit of being able to encapsulate these security functions. Security functions can be updated and hosted at a single point which prevents duplicated functions across applications and security flaws. The advantages of a token service or token based application are also outlined in the section 2.5 Token-based Authentication. Furthermore the chapter hold examples of JSON Tokens and how they are asserted. The concept of JSON Tokens is very important in token-based authentication systems and ensures confidentiality and integrity [cf. (ibid.)].

The chapter 3.2 Risk Assessment states that the Level of Assurance for Identity Proofing should be 2. The second level of assurance for identity proofing suggests that no

real-world existence of the claimed identity has to present. The other identity proofing assurance level can be looked up in chapter 2.2 Identity Proofing. The presentation of the real-existence can be either remote or physical. Furthermore the figure 3.1 suggest that since a identity should be resolved uniquely in our use case and it is ok to accept references a federation is recommended.

Identity Server4 is an ASP.NET framework that uses the specifics of OpenID Connect and OAuth 2.0 to enable Authentication and Authorization related features. Features include Authentication as a Service, which provides a centralized login logic for all applications, Single sign-on, Access Control for APIs and Federation Gateway. The Identity Server 4 will be used as a Token Server in the practical part [cf. (Brock and Dominick, n.d.)]

The project illustrating the use of Identity Server and the benefits of OpenID Connect an OAuth is a Visual Studio Project mostly written in C# and Typescript. The project example for Identity Server includes four different projects:

- Identity Server - The Identity Server is a ASP.NET Core Project with basic Implementation of an Identity Server which serves as a Token Server.
- ProjectApiNetCore - This application is a ASP.NET Core 2.0 API Application with basic API that returns the users Claims if he is authenticated.
- Angular Client - The Angular Client is a ASP.NET Core MVC Angular Project used as a Client that can be accessed by an End-User who can authenticate with the Identity Server and requests protected resources of the API ProjectApiNetCore. This project uses the Implicit Code Flow.
- MVC Client - The MVC Client is a ASP.NET Core MVC Project used as a Client that can be accessed by an End-User and can authenticate with the Identity Server and requests protected resources of the API ProjectApiNetCore. This project uses the Hybrid Code Flow.

Identity Server This project is using the IdentityServer4 library by Brock Allen and Dominick Baier. The Project works as a Token Server which means that the Identity Server Project is responsible for authentication the user, managing the identities and provide and approve tokens. Furthermore, the Identity Server implements different Authentication Flows.

IdentityServer4 adds endpoints of OAuth 2.0 and OpenID Connect to an arbitrary ASP.NET Core application as shown in 3.6. The identity server can be as complex

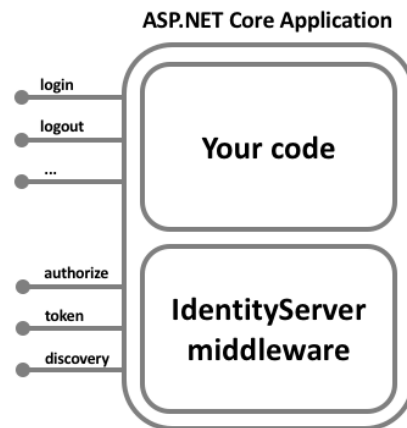


Figure 3.6: IdentityServer Middleware

as the developer wants but Brock and Dominick, n.d. recommends to keep the attack surface as small as possible by just including authentication related UI only [cf. (ibid.)].

For the basic Setup, the Identity Server has to be added to the StartUp class and to ensure a secure communication a certificate has to be created to sign the request. For the basic setup, Identity Server provides us with `DeveloperSigningCredentials` which provides a dummy certificate. In this example application, a real certificate is included.

```
PS C:\WINDOWS\system32> New-SelfSignedCertificate -type Custom -subject "CN=newsts, OU=UserAccounts, DC=acp, DC=at" -TextExtension @(
48 -curveExport CurveName -certStoreLocation -certCurrentUserMy

    PSParentPath: Microsoft.PowerShell.Security\Certificate::CurrentUserMy
Thumbprint      Subject
-----
B8397639321E28E5168BFA7195A451B1613DCF5 CN=newsts, OU=UserAccounts, DC=acp, DC=at
PS C:\WINDOWS\system32>
```

Figure 3.7: Self signed Certificate with Powershell

The certificate used in this application was created with Powershell as shown in 3.7. The algorithm used in this certificate is RSA. Depending on the algorithm that is used in the certificate a similar hashing algorithm has to be used for the Client Secret.

The API Resources include the available APIs that can be called and included in the scope of a request. The Identity Resources are Resources that can be included in the returning `id_token`. The Clients are the available Clients that can be configured and can use the Identity Server. Those Client Configurations indicate which Authorization Flow is used and how to retrieve `id_token`, `access_token`, and a possible `refresh_token`. For simplifying reasons, Identity Server provides an in Memory User Storage which can be used for Testing reasons. Other ways to define Users are via .NET Core Identity

or IdentityServer4 EntityFramework. For the purpose of this implementation this Test Users were included in the Identity Server application:

1. User1:
 - Username: bob
 - Password: bob
2. User2:
 - Username: alice
 - Password: alice

After the basic setup of the Identity Server, it can be examined if the Identity Server is running correctly by calling the discovery document. The discovery document can be used by the Clients and APIs to retrieve necessary configuration data. The Identity Server has to run at local port 5000 and in the browser navigate to <http://localhost:5000/.well-known/openid-configuration>.

```
{
  issuer: "http://localhost:5000",
  jwks_uri: "http://localhost:5000/.well-known/openid-configuration/jwks",
  authorization_endpoint: "http://localhost:5000/connect/authorize",
  token_endpoint: "http://localhost:5000/connect/token",
  userinfo_endpoint: "http://localhost:5000/connect/userinfo",
  end_session_endpoint: "http://localhost:5000/connect/endsession",
  check_session_iframe: "http://localhost:5000/connect/checksession",
  revocation_endpoint: "http://localhost:5000/connect/revocation",
  introspection_endpoint: "http://localhost:5000/connect/introspect",
  frontchannel_logout_supported: true,
  frontchannel_logout_session_supported: true,
  backchannel_logout_supported: true,
  backchannel_logout_session_supported: true,
  - scopes_supported: [
    "openid",
    "profile",
    "api",
    "offline_access"
  ],
  - claims_supported: [
    "sub",
    "name".
  ]
}
```

Figure 3.8: OpenID Discovery Document

The discovery document is located at a well-known location and is containing key-value pairs as a JSON structure. The key-value pairs in the discovery document represent multiple endpoints that are used to authenticate a user including URIs of the authorization, token, userinfo, and public-keys endpoint. The use of a discovery document brings more flexibility to the protocol. The application should have the discovery URL hard-coded in the application according to (Google, n.d.) the discovery document URL can then be used to fetch endpoints from the document and use them to for example send an authentication request [cf. (ibid.)].

The metadata that is seen in 3.8 OpenID discovery document is a mixture of required elements with some recommended ones that are implemented by the identity server. The required elements are issuer, authorization_endpoint, token_endpoint, jwks_uri, response_types_supported, subject_types_supported and id_token_signing_alg_supported. The issuer, in this case, is this Identity Servers address. The authorization_endpoint is the URL OAuth 2.0 Authorization Endpoint. The user is redirected to the authorization server's authorization endpoint for authentication and authorization. The authentication request that is sent to the authorization server can have different request parameters. These request parameters are defined by OAuth 2.0 and additional request parameters defined by OpenID Connect. The token_endpoint is the URL of the OAuth 2.0 Token Endpoint. The RP can request access or optionally refresh tokens from the token endpoint. The user_endpoint can be used to request additional information concerning the user. The response_types_supported is important information about what kind of response is supported and ultimately what kind of authentication flow can be used based on that information like described in chapter 2 in Single-Sign on Federate Systems. The subject_types_supported is a list of subject identifier types. Moreover, last but not least id_token_signing_alg_supported is used to find out which JWS is signing algorithm is used to encode the ID token and get the claims of the JWT. The algorithm RS256 must be included [cf. (Sakimura, Bradley, Jones, Medeiros, et al., 2014, (Sakimura, Bradley, Jones, and Jay, 2014))].

```
- keys: [
  - {
    kty: "RSA",
    use: "sig",
    kid: "8707eec8504cf2aaaf366585ab82fb54",
    e: "AQAB",
    n: "4E4Auc6FWI_HMxHSU30pbL92PWK8jH4nC47KXzTVHcI-u6r63JFoyATypMFGX2
    GZ18mvfn954Bw7jpI59rG4Z0bSyp1gdbxMwzLdkh9CUd__euL0BadL9kkMcjXKxMu2
    alg: "RS256"
  }
]
```

Figure 3.9: JWKS Endpoint

The jwks_endpoint is worth a closer look. JWKS SET is published to the JWKS endpoint. The keys shown in (3.9 JWKS Endpoint) can be rolled over by periodically adding new keys to the JWK Set. This also indicates if the cryptographic algorithms are configured correctly. E.g. : The message is using the kid of signing key in the JOSE Header to indicate which key has to be used to validate the signature. The algorithm used by the signing party has to be supported by the recipient and can be either and Asymmetric Signature or a Symmetric Signature. When using RSA or ECDSA signatures, the alg Header Parameter has to be set to the correct algorithm, and the private key used to sign must be associated with the public key published by

the sender. When using MAC-based signatures, the alg Header Parameter has to be set to the correct algorithm, and the MAC key is the octets of the UTF-8 representation of the client_secret. MAC-based signatures cannot be used by public Clients because they cannot keep secrets. All metadata types are listed in the specification of OpenID Discovery Document from Sakimura, Bradley, Jones, and Jay, 2014 [cf. (Sakimura, Bradley, Jones, Medeiros, et al., 2014, (Sakimura, Bradley, Jones, and Jay, 2014))].

After calling the OpenID discovery document and the JWKS endpoint, one can be ensured that the basic setup of the IdentityServer works. Next, a resource that is worth being protected by the Identity Server has to be created.

ProjectApiNetCore This ProjectApiNetcore is an ASP.NET Core application. This application represents the Resource Server and serves the Protected Resources. In this particular example, the API provides a list of Products the user bought from the company and the possibility to download the report that gives information about the current state of the product. The example API provides dummy data for the particular request. For easy testing of the API and designing the API, swagger.io is used. Furthermore, swagger.io (<https://swagger.io/>) gives a nice developer experience with an interactive API documentation. In addition, it is possible to generate code out of the swagger documentation for different programming languages with tools like NSwag (<https://github.com/RSuter/NSwag>).

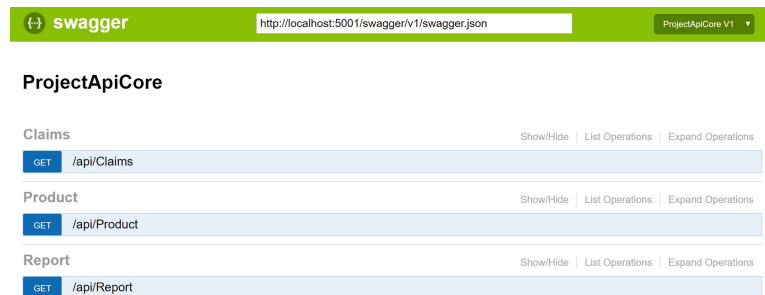


Figure 3.10: API documentation with Swagger

All of the routes shown in 3.10 API documentation with Swagger, are secured with the help of the IdentityServer4.AccessTokenValidation NuGet package. Each Controller gets an Authorize annotation. To configure the right authentication method, ASP.NET Core 2.0 offers the possibility to add the authentication to the pipeline with Dependency Injection via the method Configure Services in the Startup.class. In the StartUp class of the API Project the AddAuthentication with the Value "JwtBearerDefaults.AuthenticationSchemeMakes "Bearer" the default authentication scheme "Bearer". With the AddIdentityServerAuthentication it is defined which Token server

can be used to validate the incoming token and make sure that this token is from a trusted issuer. It adds the Identity Server access token validation handler into DI and also it is checked if the token is valid to be used with this API (aka scope). Adding `UseAuthentication` to the `Configure` method in the `Startup` class adds the authentication middleware to the pipeline so authentication will be performed automatically on every call into the host. Multiple authentication schemes can be used. A list of authentication schemes is then passed to the `Authorize` attribute separated with a comma. The default scheme results in the `HttpContext.User` property is set to that identity. After adding the Authentication logic to the API Project, the resources should be protected know. To check if the resources are protected the Swagger documentation can be used. Therefore one has to navigate to <http://localhost:5001/swagger/v1/swagger.json> and try out one of the methods shown in (3.10) API Documentation with Swagger. This should result in a 401 Unauthorized HTTP response code.

TODO: Your text here...

Chapter 4

Conclusion and Outlook

Your text here ...

Acronyms

AEAD	Authenticated Encryption and Associated Data
API	Application Programming Interface
ASP	Authentication Service Provider
CEK	Content Encryption Key
CSP	Credential Service Provider
DI	Dependency Injection
GPS	Global Positioning System
HMAC	Keyed-Hash Message Authentication Code
HTTP	Hypertext Transfere Protocol
HTTPS	Hypertext Transfere Protocol Secure
IdP	Identity Provider
IP	Internet Protocol
IT	Information Technology
JOSE	Javascript Object Signing and Encryption
JSON	JavaScript Object Notation
JWE	JSON Web Encryption
JWK	JSON Web Key
JWKS	JSON Web Key Set
JWS	JSON Web Signature
JWT	JSON Web Token
LDAP	Lightweight Directory Access Protocol
LOA	Level of Assurance
MAC	Media Access Control

MFA	Multi-factor Authentication
MVC	Multi View Controller
OTP	One-time Password
PII	Personally Identifiable Information
PIN	Personal Identification Number
PKCS	Public-Key Cryptography Standard
REST	Representational State Transfere
RMF	Risk Management Framework
RP	Relying Party
SAML	Security Assertion Markup Language
SFA	Single-factor Authentication
SHA	Secure Hash Algorithm
SOAP	Simple Object Access Protocol
SP	Service Provider
SSO	Single-sign On
STS	Security Token Service
UI	User Interface
URL	Uniform Resource Locator
UTF-8	8-bit USC Transformation Format
WS	Webservice
XML	Extensible Markup Language

Bibliography

- Birrell, E. and F. B. Schneider (Sept. 2013). “Federated Identity Management Systems: A Privacy-Based Characterization”. In: *IEEE Security Privacy* 11.5, pp. 36–48.
- Bolton, Joshua b. (n.d.). *E-Authentication Guidance for Federal Agencies*. Washington D.C.: OMB (Office of Management and Budget). Available from: <<https://georgewbush-whitehouse.archives.gov/omb/memoranda/fy04/m04-04.pdf>>.
- Boyd, R. (2012). *Getting Started with OAuth 2.0*. Oreilly and Associate Series. O’Reilly Media, Incorporated. ISBN: 9781449311605. Available from: <<https://books.google.at/books?id=qcsoLHusAFsC>>.
- Boyed, Ryan (2012). *Getting Started with OAuth 2.0 - Programming Clients for Secure Web API Authorization and Authentication*. O’Reilly Media.
- Brock, Allen and Baier Dominick (n.d.). *IdentityServer4Documentation. Release 1.0.0*. Available from: <<https://media.readthedocs.org/pdf/identityserver4/release/identityserver4.pdf>>.
- Brooks, Sean, Michael Garcia, Naomi Lefkovitz, Suzanne Lightman, and Ellen Nadeau (Jan. 2017). *An Introduction to Privacy Engineering and Risk Management in Federal Systems*. NISTR 8062. NIST (National Institute of Standards and Technology).
- Cirani, Simone, Marco Picone, Pietro Gonizzi, Luca Veltri, and Gianluigi Ferrari (Feb. 2015). “IoT-OAS: An OAuth-Based Authorization Service Architecture for Secure Services in IoT Scenarios”. In: 15, pp. 1224–1234.
- Corre, Kevin, Oliver Barais, Gerson Sunyé, Frey Vincent, and Jean-Michel Crom (2017). *Why can’t users choose their identity provider*. Available from: <<https://petsymposium.org/2017/papers/issue3/paper18-2017-3-source.pdf>> [May 2018].
- Dasgupta, Dipankar, Roy Arunava, and Nag Abhijit (2017). *Advances in User Authentication*. Springer International Publishing AG. ISBN: 978-3-319-58808-7.

- Google, Inc. (n.d.). *Developers Google. Google Identity Platform*. Google Inc. Available from: <<https://developers.google.com/identity/protocols/OpenIDConnect#discovery>>.
- Grassi, Paul A., James L. Fenton, Naomi B. Lefkovitz, Jamie M. Danker, Yee-Yin Choong, Kirsten K. Greene, and Mary F. Theafanos (July 2017). *Digital Identity Guidelines. Enrollment and Identity Proofing*. Special Publication 800-63A. NIST (National Institute of Standards and Technology).
- Grassi, Paul A., James L. Fenton, M. Newton Elain, Ray A. Perner, Andrew R. Regenscheid, William E. Burr, Justin P. Richer, Naomi B. Lefkovitz, Jamie M. Danker, Yee-Yin Choong, Kirsten K. Greene, and Mary F. Theafanos (Apr. 2014). *Recommended Security Controls for Federal Information Systems and Organizations*. Special Publication 800-53 Revision. NIST (National Institute of Standards and Technology).
- (July 2017). *Digital Identity Guidelines. Authentication and Lifecycle Management*. Special Publication 800-63B. NIST (National Institute of Standards and Technology).
- Grassi, Paul A., Michael E. Garcia, and Fenton James L. (July 2017). *Digital Identity Guidelines*. Special Publication 800-63-3. NIST (National Institute of Standards and Technology).
- Grassi, Paul A., Justin P. Richer, Sarah K. Squire, James L. Fenton, Ellen M. Nadeau, Naomi B. Lefkovitz, Jamie M. Danker, Yee-Yin Choong, Greene K. Kirsten, and Mary F. Theafonos (July 2017). *Digital Identity Guidelines. Federation and Assertion*. Special Publication 800-63C. NIST (National Institute of Standards and Technology).
- Hardt, D. Ed. (n.d.). *The OAuth 2.0 Authorization Framework*. Internet Engineering Task Force (IETF). Available from: <<https://tools.ietf.org/html/rfc6749>>.
- Hudson, Harris (n.d.). *Targeted Security Risk Assessments Using NIST Guidelines*. Tripwire. Available from: <<https://www.tripwire.com/state-of-security/risk-based-security-for-executives/risk-management/targeted-security-risk-assessments-using-nist-guidelines/>>.
- Inc., Google (July 2018). *Google Developers. OAuth 2.0 Playground*. Available from: <<https://developers.google.com/oauthplayground/>> [July 2018].
- JerichoSystems (2018). *Identity Silo*. Available from: <https://www.jerichosystems.com/technology/glossaryterms/identity_silo.html> [June 2018].

- Jones, M. (May 2015). *JSON Web Algorithms (JWA)*. Internet Engineering Task Force (IETF). Available from: <<https://tools.ietf.org/html/rfc7518>> [July 2018].
- Jones, M., J. Bradley, and Sakimura N. (May 2015). *JSON Web Signatures (JWS)*. Internet Engineering Task Force (IETF). Available from: <<https://www.rfc-editor.org/rfc/pdf/rfc7515.txt.pdf>> [July 2018].
- Jones, M., J. Bradley, and N. Sakimura (2015). *JSON Web Token (JWT)*. Internet Engineering Task Force (IETF). Available from: <<https://tools.ietf.org/html/rfc7519>> [July 2018].
- Jones, M. and J. Hildebrand (May 2015). *JSON Web Encryption (JWE)*. Internet Engineering Task Force (IETF). Available from: <<https://www.rfc-editor.org/rfc/pdf/rfc7516.txt.pdf>> [July 2018].
- KeyCloack (n.d.). *Sever Administration Guide - KEYCLOAK. Keycloak 1.9.8.Final*. published with GitBook. Keycloak <http://www.keycloak.org>. Available from: <https://www.keycloak.org/docs/1.9/server_admin_guide/topics/sso-protocols/saml-vs-oidc.html>.
- LeBlanc, Jonathan (n.d.). *Programming Social Applications*. Ed. by Mary Tresler. Sebastopol, CA 95472: O'Reilly Media, Inc. ISBN: 978-1-449-39491-2.
- Lodderstedt, Torsten (n.d.). *OpenID Connect: Login mit OAuth, Teil 1 – Grundlagen*. heise.de. Available from: <<https://www.heise.de/developer/artikel/OpenID-Connect-Login-mit-OAuth-Teil-1-Grundlagen-2218446.html?seite=all>>.
- Lynch, Lucy (Sept. 2011). “Inside the Identity Game”. In: *IEEE Internet Computing* 15.5, pp. 78–82.
- Neumann, Peter G. (2013). *Principled Assuredly Trustworthy Composable Architectures*. Available from: <<http://www.csl.sri.com/users/neumann/chats4.pdf>> [May 2018].
- NIST (National Institute of Technology), U.S. Department of Commerce (Sept. 2012). *Guide for Conducting Risk Assessment. Information Security*. Special Publication 800-30. NIST (National Institute of Standards and Technology).
- Pashalidis, Andreas and Chris J. Mitchell (2003). “A Taxonomy of Single Sign-On Systems”. In: *Information Security and Privacy*. Ed. by Rei Safavi-Naini and Jennifer Seberry. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 249–264. ISBN: 978-3-540-45067-2.
- Prasad, Prakhar (Oct. 2016). *Mastering Modern Web Penetration Testing*. Ed. by Julian Ursell. Ed. by Rahul Nair. Ed. by Amrita Noronha. Ed. by Shweta H. Birwatkar. Birmingham: Packt Publishing Ltd. ISBN: 978-1-78528-458-8.

- Procházka, Michal, Daniel Kouřil, and Luděk Matyska (May 2010). “User centric authentication for web applications”. In: *Collaborative Technologies and Systems (CTS)*. Chicago, IL, USA: IEEE. ISBN: 978-1-4244-6622-1.
- Røssvoll, Till Halbach (2013). “Reducing the User Burden of Identity Management: A Prototype Based Case Study for a Social-Media Payment Application”. In: *The Sixth International Conference on Advances in Computer-Human Interactions*. Ed. by Lothar Fritsch, pp 364-370. ISBN: 978-1-61208-250-9.
- Sakimura, N., J. Bradley, M. Jones, and E. Jay (Nov. 8, 2014). *OpenID Connect Core 1.0 incorporating errata set 1*. Available from: <http://openid.net/specs/openid-connect-discovery-1_0.html> [Aug. 8, 2018].
- Sakimura, N., J. Bradley, M. Jones, B. de Medeiros, and C. Mortimore (Nov. 8, 2014). *OpenID Connect Core 1.0 incorporating errata set 1*. Available from: <http://openid.net/specs/openid-connect-core-1_0.html#toc> [June 22, 2018].
- Sakimura, N., J. Bradley, M. Jones, B. de Medeiros, and C. Mortimore (n.d.). *OpenID Connect Core. 1.0 incorporating errata set 1*. Available from: <http://openid.net/specs/openid-connect-core-1_0.html#toc>.
- Saltzer, Jerome H. and Michael D. Schroeder (1975). *The Protection of Information in Computer Systems*. Available from: <<http://www.cs.virginia.edu/~evans/cs551/saltzer/>> [June 2018].
- Schwartz, Mike (n.d.). *OAuth vs. SAML vs. OpenID Connect*. Available from: <<https://www.gluu.org/blog/oauth-vs-saml-vs-openid-connect/>>.
- Sevilleja, Chris (Jan. 21, 2015). *The ins and outs of Token Based Authentication*. Scotch.io. Available from: <<https://scotch.io/tutorials/the-ins-and-outs-of-token-based-authentication>> [July 2018].
- Siriwardena, Prabath (Apr. 2016). *JWT, JWS and JWE for Not So Dummies! (Part 1)*. Available from: <<https://medium.facilelogin.com/jwt-jws-and-jwe-for-not-so-dummies-b63310d201a3>> [July 2018].
- Spencer, Travis (n.d.). *API Security: Deep Dive into OAuth and OpenID Connect*. Nordic APIs. Available from: <<https://nordicapis.com/api-security-oauth-openid-connect-depth/>>.
- Standards, NIST (National Institute of and Technology) (n.d.). *Risk Management. Risk Management Framework (RMF) Overview*. Available from: <[https://csrc.nist.gov/Projects/Risk-Management/Risk-Management-Framework-\(RMF\)-Overview#1](https://csrc.nist.gov/Projects/Risk-Management/Risk-Management-Framework-(RMF)-Overview#1)>.
- Standards, NIST (National Institute of and Technology)) (n.d.). *Federal Informataion Processing Standard Publication. Standards for Security Categorization of Fed-*

eral Information and Information Systems. NIST. Available from: <<https://csrc.nist.gov/csrc/media/publications/fips/199/final/documents/fips-pub-199-final.pdf>>.

Steiner, Peter (2018). “On the Internet, nobody knows you’re a dog”. In: *The New Yorker* (). Available from: <<http://archives.newyorker.com/?iid=15713&startpage=page0000063#folio=CV1>> [July 2018].

Tkalec, Tino (2015). *JSON Web Token Tutorial. An Example in Laravel and AngularJS*. Toptal. Available from: <<https://www.toptal.com/web/cookie-free-authentication-with-json-web-tokens-an-example-in-laravel-and-angularjs>> [July 2018].

Todorov, Dobromir (2007). *Mechanics of User Identification and Authentication - Fundamentals of Identity Managment*. Auerbach Publications. ISBN: 978-1-4200-5219-0.

Tomkins, Benjamin (2009). “Dealing With Password Fatigue”. In: *Forbes*.

Xu, Fangyuan (n.d.). “Security and Privacy Concern for Single Sign-on Protocols”. Project. Tufts University. Available from: <<http://www.cs.tufts.edu/comp/116/archive/fall2015/fxu.pdf>>.