Service-to-Service Authentication in a Microservice Deployment

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Declaration

I hereby declare and confirm that this thesis is entirely the result of my own original work. Where other sources of information have been used, they have been indicated as such and properly acknowledged. I further declare that this or similar work has not been submitted for credit elsewhere. This printed copy is identical to the submitted electronic version.

Hagenberg, January 31, 2022

Benjamin Ellmer

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Abstract

This should be a 1-page (maximum) summary of your work in English.

Kurzfassung

An dieser Stelle steht eine Zusammenfassung der Arbeit, Umfang max. 1 Seite. ...

Chapter 1

Introduction

In the past years, a trend towards highly-scalable software systems like the microservice architecture emerged. The migration from the monolithic approach towards microservices has enormous consequences regarding the security of software systems [15]. Function calls within the same project migrate to remote calls over the network [4]. This offers a larger attack surface because intruders could spoof the communication among the services. Therefore the communication among the services has to provide authentication to prevent attackers from exploiting the system. Additionally, service-to-service communication has to provide confidentiality. Confidentiality is usually addressed using TLS, which also provides authentication, but it only authenticates the server to the client. Therefore additional authentication mechanisms are necessary to implement mutual authentication. The most popular approaches for service-to-service authentication are mutual TLS (mTLS) and authentication using self-signed JSON Web Tokens (JWT) [5]. This thesis will describe and compare this mechanism to work out differences, advantages, and disadvantages.

1.1 Motivation

The International Data Corporation (IDC) has predicted that by 2022, 90% of all apps will feature microservice architectures [23]. So it is inevitable to deal with the numerous mechanisms to secure such systems properly. Authentication is one of the most crucial security challenges. When authentication is neglected, attackers could perform attacks like the Main-in-the-middle-Attack to exploit the system, even if other security challenges like confidentiality are managed. Such attacks could result in substantial data leaks or allow attackers to misuse the system for their advantage.

The microservice architecture is based on having multiple services running in multiple locations. This results in a bigger attack surface because multiple machines are exposed to the internet, making it simpler to find vulnerabilities. This is one of the reasons why Netflix received massive attacks on their microservice based-systems in the past years [14].

This motivation shows how vital microservice security is, and the aim of this thesis aims to help microservice developers choose the correct authentication mechanisms for their projects.

1.2 Challenges

Since the microservice architecture became as popular as in the last years, there is a lack of evaluation research and only limited insight into the particular security concerns, especially regarding service-to-service authentication. The most popular solutions and existing implementations are closed source, like the mTLS Architecture of Netflix. Other freely available approaches are often poorly documented and therefore hard to understand [20].

Additionally, the migration from the monolithic architecture to the microservice architecture results in a performance overhead [18]. Furthermore, the authentication mechanisms produce high latencies since the services have to communicate to centralized authorities sometimes. So the mechanisms have to be implemented very efficiently, and caching should be applied to minimize the resulting performance overhead.

The microservice architecture and the service-to-service authentication bring some more challenges and difficulties, which will be declared and discussed in the following chapters.

1.3 Chapter Overview

Chapter 2 introduces essential fundamentals of the microservice architecture. It should explain why the later discussed authentication mechanisms are a requirement caused by the microservice architecture.

Chapter 3 summarizes the state-of-the-art concepts regarding microservice security and public key-based authentication. Furthermore, it describes the fundamentals of the required technologies for the later discussed authentication mechanisms.

Chapter 4 describes the two compared authentication mechanisms in detail. Especially the advantages and disadvantages between those authentication concepts are discussed.

Chapter 5 shows the backend of an app, which implements the discussed authentication mechanisms. Additionally, it provides some implementation details using the ASP.Net framework.

Chapter 6 describes the setup of a performance experiment of the authentication mechanisms. The experimental results are then interpreted and discussed.

Chapter 2

Microservice Architecture

This chapter introduces the microservice architecture concepts, which are necessary to understand why the later discussed approaches are needed. The principles used to design microservices lead to some characteristics, resulting in the motivations and challenges declared in this chapter. Furthermore some recommendations about the use cases of the microservice architecture are provided and the caused security consequences are declared.

2.1 Motivation

Companies like Netflix, Amazon, and Uber are front-runners for building software solutions using the microservice architecture [5]. The main idea is to split the business logic of an application into small autonomous services that work together. This means the programmers have to avoid the temptation of developing too large systems. This approach results in the following benefits [12]:

- Technology heterogeneity is achieved through the possibility to use different technology stacks for different services, depending on the needs of the services. It is even possible to use different data storage for the different microservices (e.g., graph database for users).
- Resilience is achieved since component failures can be isolated, so the rest of the system can carry on working by degrading the functionality of the system.
- Scaling is much more effective due to the possibility to scale only the parts of the system that really need scaling.
- The deployment is much more convenient because a single microservice can be deployed instead of deploying the whole application, even for small changes.
- The organizational alignment can be improved by assigning the work to small teams that work on smaller codebases, resulting in higher productivity.
- Composability is achieved, considering that the functionalities can be consumed in different ways for different purposes.
- Replaceability is optimized since rewriting a tiny service is much more manageable than replacing a few parts of a vast application.

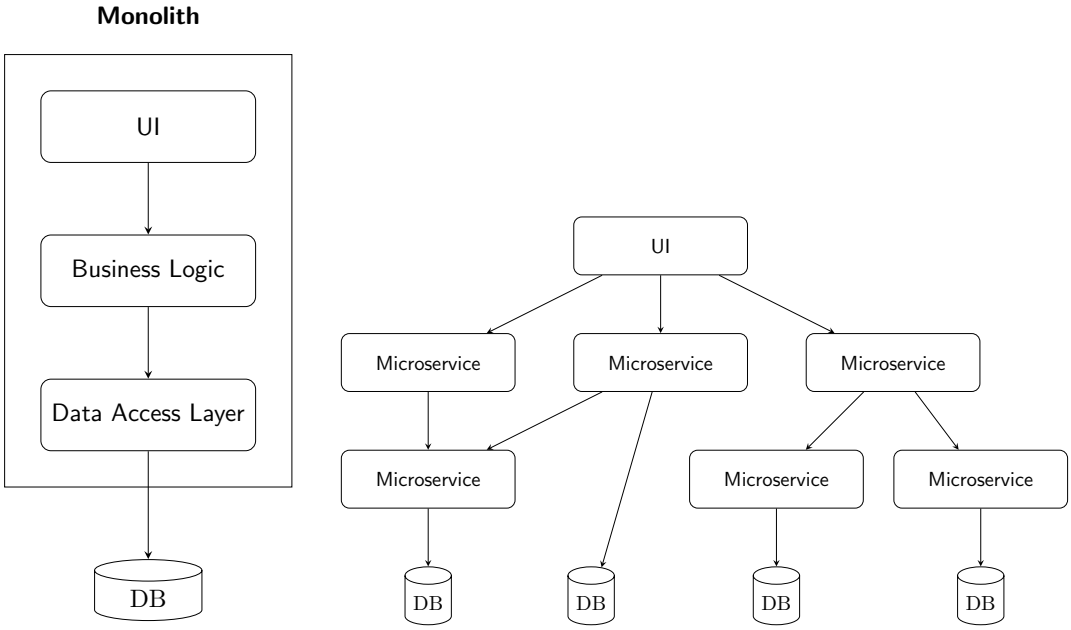

Figure 2.1: Example of monolithic architecture and a microservice architecture [9]

2.2 Comparison to the Monolithic Architecture

Figure 2.1 shows the architectural differences between monolithic and microservice applications. A monolithic application has a single unit containing the user interface layer (UI), the business logic layer, and the data access layer. Therefore it is much simpler to manage but brings the following downsides regarding the codebase [9]:

- New features and modifications of old features are harder to implement.
- Refactoring changes can reflect many parts of the software
- Code duplication raises since it is almost impossible to reuse existing code

The microservice architecture consists of multiple services focused on only one function of the business logic. Those services communicate with other services using remote calls (e.g., over HTTP), which causes higher latencies. Depending on the needs of the services, each service can have its own database, which can differ from the database system of the other services. It is also possible to share one database for multiple services, but this should be avoided to reduce coupling between the services.

2.3 Design Principles

It is hard to define principles, which will apply to all microservice architectures, but according to Newman, most of them will adhere to the following principles [12]:

Modelled around business concepts: The functionalities are structured around the business contexts instead of the technical concepts.

Adopting culture of automation: The microservice deployments embrace the culture of automation by using automated tests, continuous delivery, automated servers, and much more automation tools.

Hiding implementation details: The microservices hide as many implementation details as possible to avoid coupling. Especially the databases of the services should be hidden and can be accessed by other services using APIs.

Decentralising all The things: All approaches that could centralize business logic are avoided to keep associated data and logic within the service boundaries.

Independently deployed: The microservices should provide the possibility to deploy them without having to deploy any other service. Therefore the autonomy of the teams can be increased, and new features can be released faster.

Isolates failures: The microservices have to deal with misbehaving parts of the system and keep on providing as much functionality as possible, to prevent cascading failure.

Highly observable: It is not sufficient to observe a single service's behavior and status. Instead, the functioning of the whole system has to be monitored.

2.4 Challenges

There are some benefits of using the microservice architecture. It also introduces a set of challenges, which could argue to avoid the microservice architecture in some cases. According to Kalske et al. [9] the microservice architecture brings the following technical challenges with it:

- The declaration of the service boundaries is very hard [9], especially if the developers do not know the domain that well [12].
- The services should not become too fine-grained to prevent performance overhead. Otherwise, if they are not decomposed enough, changes to one service can affect multiple services.
- Continuous Delivery and Continuous Integration are necessary to manage the services and validate their functionality.
- The integration of the services into other services can become very hard due to the requirement to be available for all used technologies.
- Good logging mechanisms have to be used to recognize failures of microservices as soon as possible.
- Fault tolerance mechanisms have to be implemented to react to situations in which needed services do not respond.

The microservice architecture is gaining popularity, even if it produces so many challenges, showing how crucial its advantages are.

2.5 Usage Situation

According to Newman [12] it is better to start with a monolithic application if the architect does not fully understand the domain and has problems declaring the boundaries

for the services. In such cases, it is better to spend some time learning what the system does first and then break things down to microservices when the system is stable. Furthermore, Newman recommends eliminating legacy monitoring systems before splitting the application into more and more microservices. Otherwise, it could get very messy to stay in knowledge about the system's status.

Fowler [24] recommends considering microservices only when a system gets too complex to manage as a monolith. His essence is keeping the system simple enough to avoid the need of microservices since the microservice architecture can slow down the development considerably. The correlation between the development productivity and the complexity of a system comparing the microservice architecture with a monolithic architecture is shown in figure 2.2.

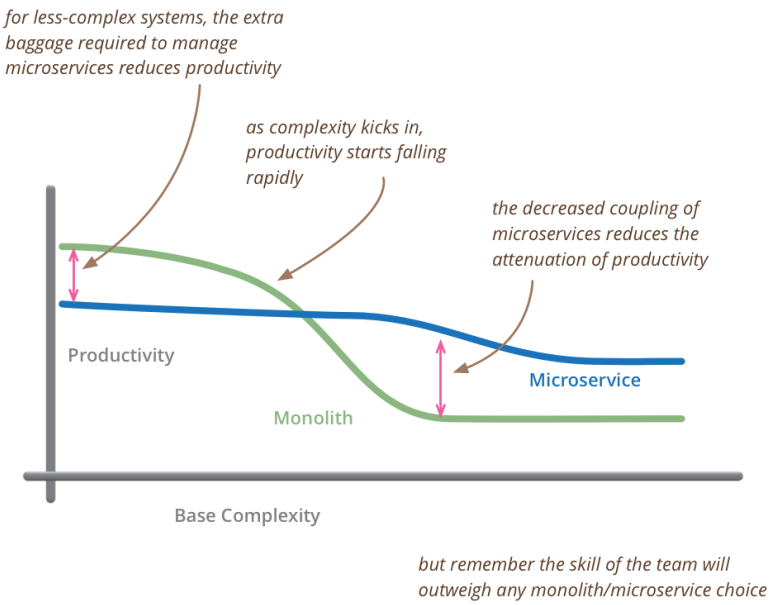

Figure 2.2: Correlation between base complexity and productivity in a microservice architecture compared to a monolithic architecture [24]

2.6 Security Consequences

The migration to the microservice architecture brings many consequences regarding the security of a deployment. Especially the network communications among the services introduce a set of vulnerabilities. Confidentiality, integrity, and availability have to be assured. The need for authentication mechanisms is a common issue of network security, but the migration from language-level calls to remote calls causes the need for authentication between microservices. Therefore, the authentication mechanisms discussed in this thesis are a consequence of the microservice architecture and can be neglected with a monolithic architecture.

Chapter 3

Related Work

This chapter summarizes the state-of-the-art concepts for microservice security, public key-based authentication, and the later required technologies. Service-to-service authentication is only one part of microservice security. Therefore all related topics, considering microservice security, are shortly described. Furthermore, the concepts of public-key authentication are discussed since the authentication mechanisms compared in this thesis are based on public-key cryptography.

3.1 Microserivce Security

Siriwardena and Dias [5] gave an extensive guide of all topics related to microservice security. They separated the security of a microservice deployment into edge-level security and service-level security. Since the microservice architecture splits the backend into multiple minor services, it is insufficient to secure the system only on the edge or service level. Each part of the system must be appropriately secured regarding confidentiality, authentication, and authorization.

3.1.1 Edge-level security

Edge-level security is defined as the security mechanisms that protect the resources within the deployment from attackers located outside the deployment. The API Gateway is responsible for edge security. It is the only entry point to the microservice deployment. The API Gateway intercepts all requests targeted for the APIs of the services. After validating the requests, it dispatches the valid ones to the microservices. The main tasks of an API Gateway are authentication of the end-user, authorization, and throttling [5]. It authenticates the end-user using access tokens, which come from access delegation technologies like OAuth 2.0 or Open ID Connect [16]. By outsourcing the end-user authentication to the API Gateway, it has to be performed only once by the API Gateway and not multiple times by each service [5]. The API Gateway can perform authorization for all microservices. In most cases authorization is performed the edge-level and the service-level. The API Gateway performs only coarse authorization assertions, to prevent having a single-point-of-decision [2].

3.1.2 Service-level security

Service-level security is defined as the security mechanisms that protect the communication among the microservices. According to Barabanov and Makrushin [2] service-level security can be decomposed into the sub-functions service-level authentication, service-level authorization, and external identity propagation. Service-level security can either be implemented by the microservices themselves or a service-mesh. A service mesh can be seen as a dedicated infrastructure layer, which manages the service-to-service communication of containerized services. In a typical microservice deployment with a service mesh, each microservice has its service proxy, which works transparently [5]. The service mesh takes care of service discovery, routing, load balancing, traffic configuration, authentication, authorization, and monitoring [4]. Therefore the services can focus on exactly the tasks they are intended for and do not have to care about security-related tasks [5].

Service-to-service-authentication

Authentication is the process of identifying the communication partner to protect a system from spoofing. Since the communication among microservices is done using remote calls, their communication has to provide authentication [5]. Service-to-service authentication can be implemented in the following ways [5]:

- Trust the Network (TTN)
- mutual Transport Layer Security (mTLS)
- self signed JSON Web Tokens (JWTs)

Trust the Network is a security approach based on the assertion that nobody has access to the components within a network perimeter. All components rely on network security. Nevertheless, internal misbehavior can lead to exploits allowing attackers to intrude into the network perimeter and exploit the microservices [21]. Therefore the industry is heading towards zero-trust networks, and the TTN approach is not more used as primary authentication mechanism [2].

Service-to-service authentication based on mTLS and self-signed JWTs will be discussed in more detail in chapter 4.

Service-level authorization

Authorization defines the tasks that a principal is allowed to perform on a system. It requires that the principal is already authenticated because the authorization is performed based on the identity [16]. Service-level authorization gives the microservices more control to enforce access control. The authorization is usually performed using policy decision point (PDP) models like the centralized PDP model or the embedded PDP model [2, 5]. Proper service-to-service authentication mechanisms are a precondition for service-to-service authorization since the authorization can be bypassed with insufficient authentication [16].

External entity identity propagation

In order to perform the authorization correctly, the services have to know the context of the caller. The most popular technic for identity propagation is extracting the user's context within JSON Web Tokens. The tokens are passed between the microservices and the API Gateway. The propagated identity of the user can be extracted from the token, and the token's signature must be checked. The microservices can perform authorization based on the identity of the client [2, 5]. The chosen authentication mechanism has an impact on identity propagation. This will be discussed in more detail in chapter 4.

3.2 Public key-Based Authentication

Authentication can be achieved in multiple ways Two common approaches are symmetric cryptography and public-key cryptography. Both authentication mechanisms discussed in chapter 4 are based on public-key cryptography. Public key cryptography provides higher security than symmetric cryptography. Therefore it is the preferred method to implement authentication mechanisms, although it requires higher computation and communication costs than symmetric cryptography [3].

3.2.1 Public key cryptography

Public key cryptography is also called asymmetric cryptography because the main idea is that different keys are used for encryption and decryption [1]. Each participant is required to own at least one key pair. A key pair consists of a public key available to everyone and a private key that is only known by the owner of the key pair. Encrypting a message with the public key allows many people to encrypt messages so that only the person who owns the private key can read them. Furthermore, it allows one person to encrypt messages in a way that many people can read by encrypting the message with the private key [7]. This is also known under the term digital signature. Digital signatures can be used to provide authentication and integrity for messages [1].

The commonly used algorithm for digital signatures is RSA. RSA is based on factoring, its encryption key consists of the modulus N, which is hard to factor. The modulus N is calculated by multiplying the large prime number p and q with each other. Additionally the encryption key has a public factor e that has no common factors with either $p-1$ or $q-1$. The private key consists of the factors p and q, which have to be kept secret [1]. The person that knows the private key can encrypt a message using the following formula, where M is the message, and C is the encrypted message [1]:

$$C = M^e (modN)$$

An encrypted message can be decryped using the following formular:

$$M = \sqrt[e]{C(modN)}$$

Only the owner of the private key can simply calculate the message from the cipher, using the Fermat's little theorem[1].

[1] See [25] for further information

The problem with asymmetric cryptography is that the encryption and decryption times are worse than symmetric cryptography. The restriction to use only asymmetric cryptography could decrease the system's performance. Therefore it is common sense to use hybrid systems as done in TLS. In TLS, public-key cryptography is used for authentication and key exchange, but symmetric cryptography is used to provide confidentiality for the communication [7]. Henriques [7] showed that the performance of the system can be improved using a hybrid approach.

3.2.2 PKI

Public key cryptography assumes that the receiver of a message already knows and trusts the sender's public key. Public Key Infrastructures (PKI) are used to achieve this assertion. They are responsible for providing a possibility to retrieve the public key of a participant in a trusted way. This is done using Certificate Authorities (CA) and certificates. CAs sign certificates, and each communication partner who trusts the CA trusts the certificates signed by it. For this purpose, usually, X.509 certificates are used [1].

A PKI can either be an open PKI (global) or a closed PKI (self-hosted). Closed PKIs have a specific bounded context [8]. A common use case for closed PKIs is microservice deployments because they are usually company intern and have a specific bounded context [5]. The project, which is reviewed in chapter 5 makes use of a closed PKI created with OpenSSH. Closed PKIs are a popular option because they allow risk management and provide secrecy of its code. Open PKIs can be inspected by the public, and based on the inspection, it is determined whether the PKI is trusted or not. Certificates are retrieved by making partnerships with CAs. The main advantage is that no proprietary software is needed since the PKIs are managed by the PKI vendors [8].

3.2.3 Key Management

Key management is a requirement for public key based authentication. It results in being the most challenging part for the later discussed mechanisms. When the key management is very weak, it will have consequences for all parts of the system. Especially service-to-service authentication is affected by the quality of the key management. The authentication mechanism can not stay secure when the keys of the participants are compromised [5, 6]. According to Fumy et al. [6], a key management service has to implement the following tasks:

Entity Registration: The service must provide a procedure to create a link between an authenticated identity and its keys.

Key Generation: The service must provide a procedure to create key pairs with good cryptographic quality.

Certification: The service must provide a procedure for issuing certificates. Certification is often a part of key distribution.

Authentication/Verification: The service must provide a procedure to guarantee entity authentication, message content authentication, and message origin authentication.

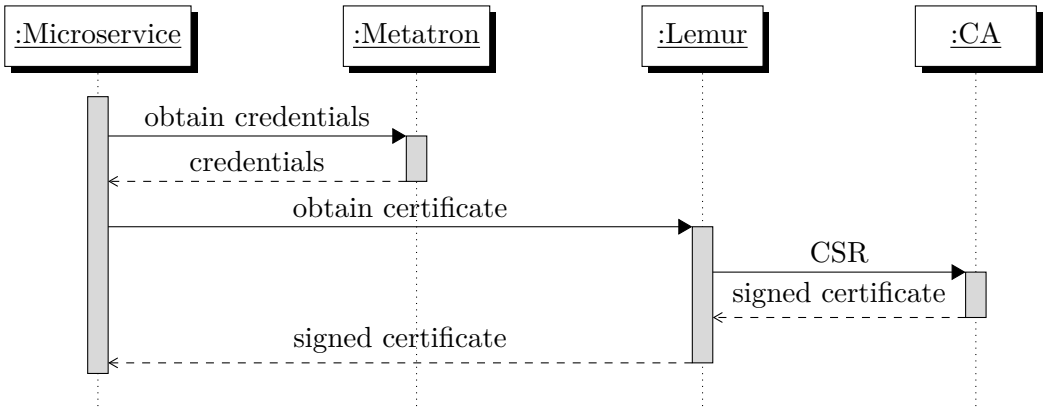

Figure 3.1: Key provisioning of netflix using Lemur and Metatron [5]

Key Distribution: The service must provide a procedure to supply keys for parties legitimately asking for them.

Dias and Siriwardena [5] furthermore give insights into the key provisioning (distribution) process of Netflix. Netflix uses its own broker called Lemur for the key provisioning. It is performed in the following steps, which are visualized in figure 3.1:

1. During the continuous delivery process, each microservice gets a set of credentials that are good enough to access the Lemur APIs. This is done using a Netflix internal tool called Metatron. Metatron credentials are long-lived credentials. They can be used for a longer timer period and the following steps can be repeated multiple times.
2. The microservice talks to the Lemur API to obtain a signed certificate for its credentials. This can happen either during the startup process of the microservice or when the microservice is rotating its keys.
3. Lemur creates a certificate signing request (CSR) addressed to the CA.
4. The certificate is signed using the CA. Lemur is not a CA, but it knows how to integrate with a CA to generate signed certificates.
5. Lemur returns the signed certificate to the microservice, who can then use it to authenticate itself to other services.

Therefore the developers do not have to worry about creating and signing certificates. Instead, they have to implement the communication with the Lemur API.

3.3 Technologies

3.3.1 X509.Certificate

X.509 certifcates bind the subject of a certificate to a public key. They are used to assure the user of a certificate that the certificate's subject owns the corresponding private key. The most significant advantage of certificates is that they can be exchanged using untrusted communication channels because the signature is not valid anymore

when the content of a certificate is changed. Therefore manipulations can be detected, and manipulated certificates can be declined [26].

When a client wants to consume a service hosted on a server, it has to obtain the server's certificate. If the client does not know the public key of the CA who signed the server's certificate, he has to obtain it. Obtaining the public key often results in chains because the client may have to work his way up until he reaches a CA he trusts. Such chains are also called certification paths [26].

Depending on the version, a certificate can include more or less information. The information is always stored inside the tbsCertificate, signatureAlgorithm, and signatureValue fields and can be expanded using extensions.

TBSCertificate: contains the data of the certificate, including the subject of the certificate, the issuer of the certificate, the public key of the subject, the validity period, and additional information [26].

signatureAlogrithm: stores the information, which cryptographic algorithm was used to sign the certificate. Algorithms are declared by their identifier, the "OBJECT IDENTIFIER". The most commonly used algorithms are the RSA algorithm and the Digital Signature Algorithm (DSA) [26].

signatureValue: contains the value of the digital signature. It is obtained by signing the content of the tbsCertificate, using the algorithm specified in the signatureAlgorithm field. The signature is used to verify the validity of the information embedded in the tbsCertificate field [26].

Certificate Revocation

Certificate revocation is a considerable problem with certificates. A certificate can be revocated for the following reasons:

- The Private key of the CA is compromised
- The Private key of the microservice is compromised
- The holder of the certificate is no longer the identity who requested the certificate
- The CA finds out that the parameters provided in the CSR are invalid

The hardest part about the certificate revocation is informing all participants about the revocation of a certificate. This is done using certificate revocation lists (CRL) or other revocation mechanisms. The big downside of CRLS is that the CA has to store a list of certificates, which are revocated. The clients have to retrieve this list whenever they establish a connection to a server, which causes high latencies. The latencies can be reduced by caching. Otherwise, caching also reduces the security because a certificate can be revocated during the lifetime of the cache. Especially a case in which the CA does not respond to the CRL query is tough to handle. Therefore certificate revocation is a significant downside of public-key-based authentication, even if the Online Certificate Status Protocol (OSCP) tries to remedy the situation[5].

3.3.2 JSON Web Token

A JSON Web Token (JWT) is a container that can carry authentication and authorization assertions and further information in a cryptographically safe manner. An au-

Header. Payload. Signature

eyJhbGciOiJIUzI1NiIsInR5cCI6IkpXVCJ9. eyJzdWIiOiIxMjM0NTY3ODkiLCJpYXQiOjE1MTYyMzkwMjIsInVzZXJuYW1lIjoiYmVuamFtaW4uZWxsbWVyIiwiZW1haWwiOiJiZW5qYW1pbi5lbGxtZXJAeWFob28uY29tIiwiYWRtaW4iOmZhbHNlfQ. 0ksqN71oloNvq3IrY7w72uoTgPz9Gpn08p-KSbFulY0

Figure 3.2: Sample JSON Web Token

thentication assertion can be anything that authenticates the user. Usually, usernames or e-mail addresses are used to identify a user uniquely. An authorization assertion can be any information about the access permissions of a user. For example, a JWT can include the information, whether the user is an admin or an unprivileged user [5].

Structure

A JWT is decomposed into the header, the payload, and the signature. The three parts are concatenated and separated by a dot [22]. A valid JWT could look like the JWT shown in figure 3.2.

The **header** contains metadata related to the JWT, which is usually the type of the token and the signature algorithm. The specification defines that only HS256[2] and none algorithm must be implemented by conforming JWT implementation. It is recommended to additionally implement the algorithms RS256 and ES256[3] [22, 27]. The base64 encoded header is the first part of the JWT.

The **payload** is a set of registered and custom claims. A claim is a piece of information about an entity. The JWT specification defines registered claims, which are not mandatory for all cases but should provide a good starting point for a set of valuable claims to ensure interoperability. The software architects can define custom claims on their own, depending on their needs. The custom claims registered in the IANA registry are called public claims, and those not registered in the IANA registry are called private claims [22, 27]. The base64 encoded payload is the second part of the JWT.

The chosen signature algorithm signs the base64 encoded header, the base64 encoded payload, and a secret (only with symmetric encryption like HMAC). The **signature** provides integrity for the message, and if it was signed with a private key, it additionally provides authentication [22]. The base64 encoded signature is the third part of the JWT.

3.3.3 Transport Layer Security

The Transport Layer Security (TLS) Protocol provides authentication, integrity, and confidentiality for the communication between two parties. It consists of two layers, the handshake protocol and the record protocol [17].

[2] HMAC SHA-256

[3] Elliptic Curve Digital Signature Algorithm (ECDSA) with 256-bit key

Handshake Protocol

The handshake protocol is responsible for negotiating a cipher suite and for providing authentication using X.509 certificates. The cipher suite declares the key exchange algorithm, the signature algorithm, the symmetric encryption algorithm, including the mode of the encryption algorithm and the hashing algorithm [11, 17]. The handshake varies on the key exchange method, but it can be separated into the following steps [10]:

1. The server and the client exchange Hello messages.
2. The server sends its certificate to the client.
3. The client sends a pre-master secret to the server.
4. The client and the server finish the handshake, using the independently computed master secret.

The steps of the handshake will be explained in more detail in chapter 4.1.1.

Record Protocol

The record protocol provides a secure channel for the secure communication of two parties. This is done by using the algorithms declared in the cipher suite. Confidentiality is assured, using symmetric encryption, and Message Authentication Codes (MAC) provide integrity [10, 11].

mTLS

TLS itself is also called one-way TLS because it helps the client to identify the server, but not the server to identify the client. Therefore mTLS was introduced to provide authentication in both directions. The client and the server must own a private/public key pair, so it is more suited for the communication between two systems and not between users and servers [5]. The authentication of the client is performed during the handshake. When mTLS is used, the client has presents his certificate to the server, before transferring the pre-master secret.

3.4 Conclusion

This chapter described the fundamentals to understand the details and differences between the later described authentication mechanisms. Furthermore, it was described why service-to-service authentication is needed and what additional mechanisms have to be implemented to secure a microservice deployment.

It is essential to understand that the whole system is compromised when one security mechanism does not work correctly. For example, the authorization can be affected when the authentication is neglected. Each service and each layer of the deployment has to be appropriately secured. The problem with the microservice architecture is that one compromised service can be used to compromise other services. Therefore, choosing the correct security mechanisms and understanding how they work is crucial.

Chapter 4

Authentication Mechanisms

This chapter explains the concepts and details of the two compared authentication mechanisms. Only the mTLS approach and the authentication using self-signed JWTs approach are discussed in more detail since the Trust the Network (TTN) approach is deprecated and should not be used anymore [5].

4.1 Authentication based on mTLS

Mutual TLS is the most popular option for the service-to-service authentication of microservice deployments [5]. Securing the communication with TLS already provides integrity confidentiality and authenticates the server to the client. Since TLS does not provide authentication from the client to the server, it is insufficient for service-to-service security. Therefore mutual TLS is used, which provides an efficient and straightforward approach to authenticating the client to the server.

The authentication using mTLS requires a PKI, same as TLS on the internet. It is possible to use the already existing PKI of the internet, but this would make the key management much harder and would not bring any advantages. Therefore it is good practice to use a self-hosted PKI to have a root of trust within the network [5].

When mTLS is used, the server and the client must provide a valid certificate to create a communication channel. The issuer of the presented certificates must be trusted by all communicating parties [5]. If one communication partner does not have a valid certificate, the communication is neglected. Therefore each service needs its private key and the corresponding public key. Additionally, a signed certificate, which binds the public key to the certificate's subject, is needed. The certificates of the communication partners are exchanged during the TLS handshake.

This mechanism can also be used to authenticate the end-users of an application. The term Client Certificate Authentication (CCA) is used for this context [13]. Service-to-service authentication using mTLS is an implementation of CCA, but in this approach, the client is not the end-user, instead, it is another service.

4.1.1 Handshake

The TLS handshake is used to exchange the certificates of the participants and set up the connection. The handshake steps differ between the used algorithms and versions of

the TLS protocol. The following sequence and figure 4.1 should give an overview about the steps of the TLS handshake using mutual TLS [13]:

1. The client initializes the connection by sending a **ClientHello** message to the server. The **ClientHello** message includes a list of supported cipher suites, and the randomness, which is a combination of random bytes and the current date [28].
2. The server responds with a **ServerHello**, in which he chooses one cipher suite of the **ClientHello** message. Furthermore, the **ServerHello** contains the server's randomness.
3. The server sends the **Certificate** message, containing one or more certificates, which can be used to build the certificate chain. The client validates the sent certificates with his own trusted store. If it trusts the sent certificate chain, the handshake is continued.
4. The server sends the **CertificateRequest** message, in which the trusted CAs of the server are listed. The client can use this list to choose the correct certificate he has to present for the Client Certificate Authentication.
5. The server sends the **ServerHelloDone** message, signalizing that the server finished his Hello message.
6. The client responds with his **Certificate** message, which is similar to the servers **Certificate** message, but contains the client's certificate chain.
7. The client then generates a random value, the pre-master secret, which is later used to derive symmetric keys for the cryptographic operations defined in the cipher suite. The pre-master secret is then encrypted using the server's public key. Therefore, only the owner of the corresponding private key, the server, can decrypt this message. In the end, the encrypted pre-master secret is transferred to the server within the **ClientKeyExchange** message.
8. The client has to prove that he owns the corresponding private key of the certificate he sent. Therefore he has to encrypt the hash of all previous messages with his private key. This encrypted hash is then sent to the server within the **CertificateVerify** message. The server can decrypt the hash with the certificate's public key and can calculate the hash on its own to check whether the decrypted hash is correct or not.
9. The client sends a **ChangeCipherSpec** message to signal the server that all following messages will be protected with the protection mechanisms defined in the cipher suite.
10. The last message of the handshake is the **Finished** message, which is an encrypted hash of all previous messages.
11. Same as step 9, but from the server.
12. Same as step 10, but from the server.

After the TLS handshake, both participants know the secret, that is used to encrypt and decrypt messages. The handshake would have almost the same steps when mTLS is not used. Only the **CertificateRequest** message of the sever and the **Certificate** message and the **CertificateVerify** message of the client are unique for mTLS. One special case of the handshake is that the client responds to the **CertificateRequest**

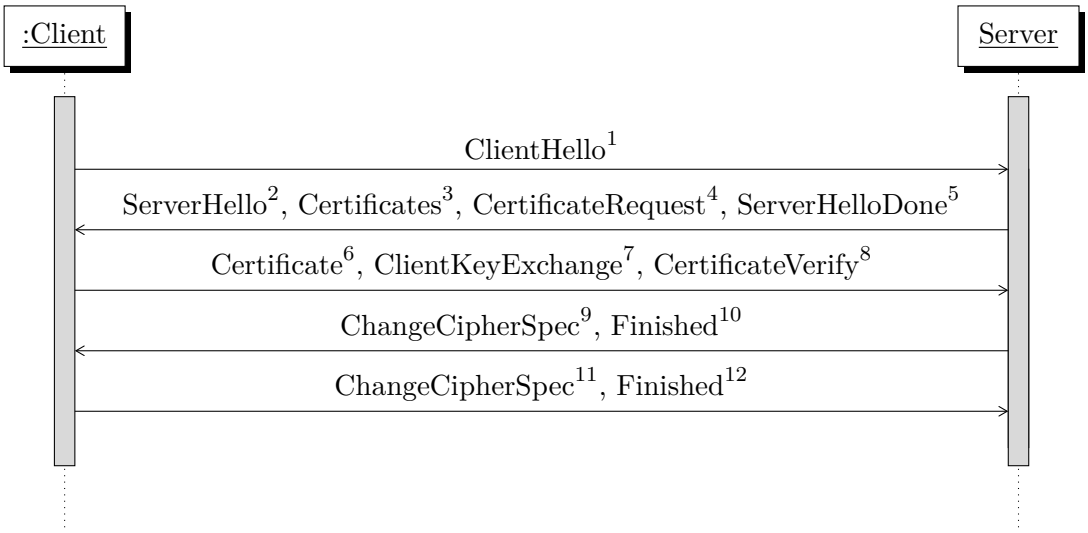

Figure 4.1: TLS handshake using mTLS [13]

with an empty **Certificate** message. Depending on the configuration of the server, the connection without a certificate can be allowed or neglected [13].

4.1.2 Passing the end user context

For some functionalities, the identity of the microservice is not relevant. Instead, the identity of the end-user is relevant. In those cases, the microservices have to pass the end-user context when they consume the logic of other microservices. The most popular approach for passing the end-user context with mTLS is JSON Web Tokens. The JWTs can be embedded within the HTTP Request body or using URL parameters. This approach can be implemented in multiple ways [5].

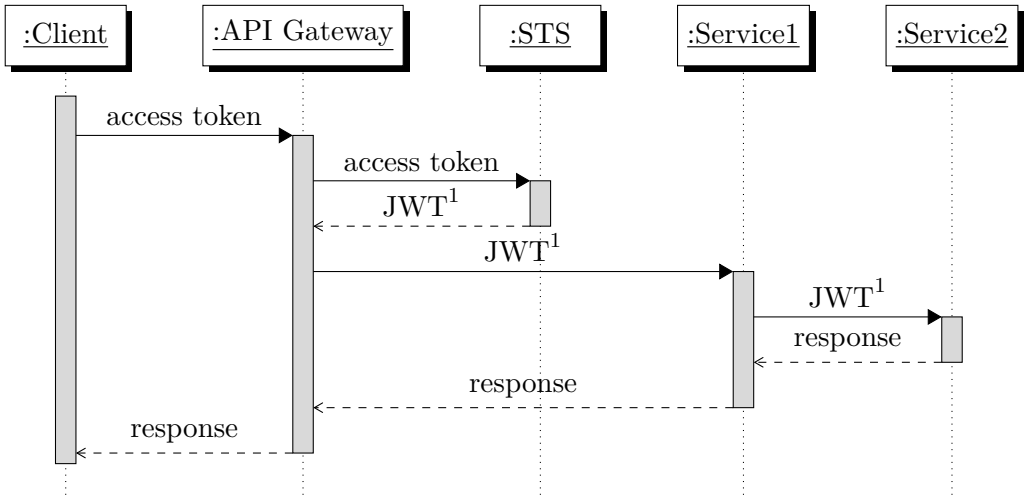

Figure 4.2: Use the same JWT for each request [5]

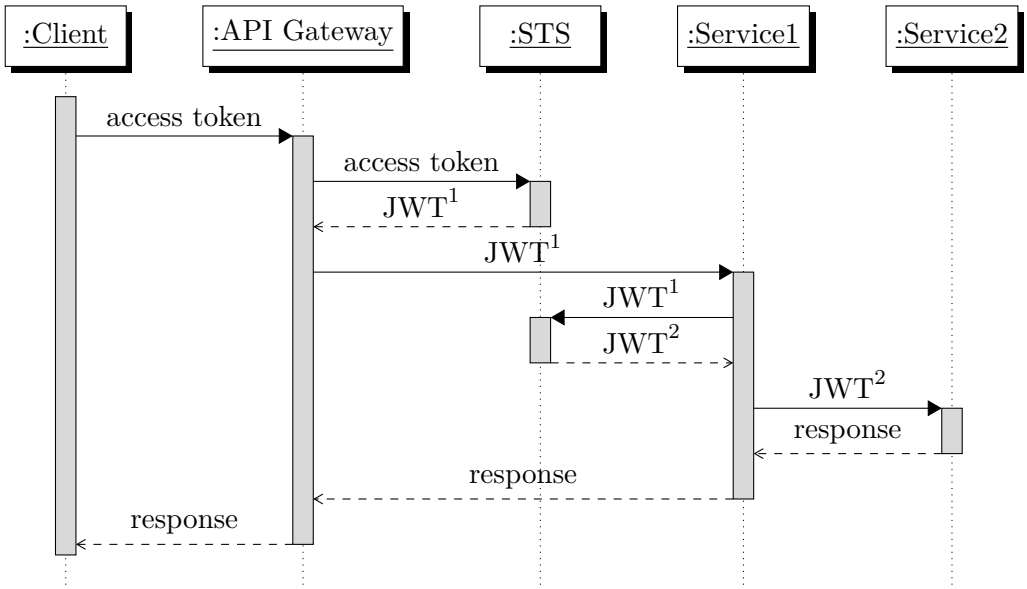

Figure 4.3: Generate new JWT for each request [5]

Generally, the user obtains an access token from any token service. This token could be an OAuth2, OpenID Connect, or any other token. The user has to send this token with each request. The token is then validated by a Security Token Service (STS). If the token is valid, the STS returns a JWT, which can then be used to consume other services. When one microservice calls another microservice, he sends the JWT, and if this microservice has to consume another microservice, he also passes the same token to the next microservice [5]. The workflow of this approach is shown in figure 4.2

Another approach is that the STS is used to generate a new token for each request like it is shown in figure 4.3. When the STS generates a new token for each request, he fully knows all performed requests. Therefore the STS could implement further authorization logic [5]. Nevertheless, the frequent calls could result in an bigger workload for the STS and decrease the system's performance.

Both approaches result in some overhead, especially the approach in which a new JWT is needed for each request. Additionally, when the microservices are located in different trust domains, those approaches can get very complicated since a microservice only trusts the STS within its trust domain [5]. The problem with the JWTs is that they can be stolen and used by intruders. Therefore it is necessary to use mTLS together with JWT.

4.1.3 Conclusion

mTLS is an efficient mechanism to implement service-to-service authentication. Since the communication between the services is usually done using HTTPS, the services already use TLS. Therefore, mTLS does not cause much configuration overhead, and no new technologies are necessary [5].

One crucial advantage of the TLS handshake is that the private keys are never

exchanged, and the session keys are always different due to the usage of the randomness. This means that even if an intruder can get the session key of a communication channel, he cannot use this key for another session. Furthermore, it is not possible to retrieve any information about the private key of the communication partners with the knowledge of the session key. This shows how secure mTLS is, even for advanced attacks [13].

From the developer's perspective, mTLS does not require much implementation logic. The service which acts as the server has to be configured to use certificate authentication. Depending on the used technologies, this is usually done by setting a few configuration parameters in the code or directly on the webserver. The service which acts as the client has to be configured to send his certificate during the TLS handshake. Most HTTP Client libraries support simply attaching the certificate to each HTTP request. Nevertheless, the developers do not have to implement much logic resulting in the problem that they do not have much control over the system. The developers have to rely on the implementation of the webserver developers. This means that if a web server has security-related bugs, the microservice developers can not solve them independently. For example, the apache webserver, one of the most popular webservers, had many issues in combination with CCA. Arnis Parsovs [13] researched the problems of the apache webserver and gave an extensive guide on how to circumvent all bugs when CCA is configured.

The biggest challenge of mTLS is the key management, which was described in more detail in the chapter 3.2.3. Key management is responsible for key provisioning, key revocation, key rotation, and more management tasks. Usually, the key management requires a self-hosted PKI for the deployment. For small applications, the key management can be kept very simple. Nevertheless, as soon as the deployment grows and many services are running simultaneously, automation tools are required. Therefore the management overhead of mTLS is much harder to handle than the implementation of mTLS itself [5].

The previously mentioned challenges and motivation result in the conclusion that mTLS is a beneficial and efficient approach when the developers do not require to fully control each aspect of the authentication. Especially when the end-user context has to be shared among the services, mTLS might not be the most efficient solution. Even if mTLS may not be the ultimate tool for all security challenges, when the requirement is service-to-service authentication, mTLS does its job, and it does it well. This is the reason why mTLS is the most popular approach for service-to-service authentication.

4.2 Authentication based on self-signed JWTs

Self-signed JWTs can be used to provide authentication for service-to-service communication. Same as mTLS, it is based on asymmetric cryptography, and each service needs to own a key pair. The main idea is that the sender creates a JWT, which is signed with his private key. The receiving service can then check the signature of the JWT with the public key of the sending service. The signed JWT is transferred within the Authorization header of the HTTP request [5]. Since the JWT does not have any fixed structure, it is possible to embed contextual data like the user context as claims within the JWT. Therefore parameters and information about the user do not have to be passed within the body or as URL parameters [5].

The usage of self-signed JWTs does not provide any confidentiality for the communication among the services. Therefore TLS should be used to provide confidentiality for the service-to-service communication. Since the authentication is not dependent on TLS, it is possible to use other mechanisms instead of TLS. For example, JSON Web Encryption or any other encryption mechanism can be used, but usually, it does not make sense to exchange TLS [5].

The usage of self-signed JWTs additionally provides non-reputability. This means each action is bound to the service that created the JWT, and the service can not repudiate that the JWT was created by him [5]. Whenever non-reputability is a requirement of the system, self-signed JWTs are the superior authentication mechanism.

4.2.1 Non Repudability

Digital signatures can be used to achieve non-reputability cryptographically. Nonrepudability binds the actions performed by a service, to the service or API Gateway who initiated the action. In general the recipient of a message is provided with a proove of the origin of the message. Therefore the recipient is protected against situations in which a sender denies that the sent a message [19].

Nonrepudability and authentication are very similar. Authentication is about convincing the other party that an event is valid. With nonrepudiation, it is even possible to prove the truth of an event to a third party [19].

A practical example in which non-reputability is useful would be an online shop. Assuming that the shop has an **OrderService** and a **PaymentService**. When the payment is sucessfully accomplished using the functionalities of the **PaymentService**, it has to signalize the **OrderService**, that the order was paied. Therefore the **PaymentService** would send a request to the **OrderService** containing a JWT signed using the private key of the **PaymentService**. When the **OrderService** stores the JWT and the request, it can always proove that the request was originated by the **PaymentService**. It could not be an other service, because only the **PaymentService** can create a valid signature for the public key of the **PaymentService**.

4.2.2 Passing the end-user context

The approaches to how the end-user context is passed between the services are similar to the approaches explained in 4.1.2. The big difference is how the JWT is transferred among the services. While with mTLS, the JWT was embedded within the body or as a URL parameter, with self-signed JWTs, it can be embedded within the JWT that already has to be transferred. This is done by appending a nested JWT within the claims of the self-signed JWT. The signature of the JWT, which is used for authentication, can still be verified by using the service's public key. The signature of the nested JWT is verified using the public key of the STS. This means the JWT is carried in a way that can not be forged. Therefore it is better to use self-signed JWTs for the authentication when the end-user context is relevant in many situations [5].

4.2.3 Conclusion

Service-to-service authentication using self-signed JWTs is not only a mechanism for authentication. It additionally provides nonrepudiation and makes sharing the user context more convenient. Otherwise, the implementation of self-signed JWTs is much more challenging than the implementation of mTLS. It is insufficient to configure the webserver correctly and append a certificate to each request. Every service has to know how to encode and decode JWTs. Furthermore, to achieve nonrepudiation, all received JWTs must be stored for an adequate timespan, requiring additional database storage.

One major advantage of the authentication using self-signed JWTs is, that the developers can vary the implementation depending on their needs. For example the developers can vary the technology used to provide confidentiality, even if this might not be necessary in most cases, the possibility can be an advantage [5]. Furthermore the developers can define additional parameters, which have to be provided within the transferred JWTs. This freedom of choice is not guaranteed with mTLS, because it is a strictly defined protocol and has very few configuration options.

Sadly the biggest challenge of mTLS, which is the key management, can not be avoided using self-signed JWTs, because it also requires each service to have its key pair. But, the key management can be simplified since it is unnecessary to have a CA responsible for signing each certificate. Still, regarding the webserver setup, it makes sense to have one superior authority, that is, the root of trust and whose chained certificates are trusted.

As a result, self-signed JWTs are the preferred authentication mechanism when the target is to achieve nonrepudiation or when the system is very dependent on sharing the user context. Nevertheless, this leads to additional implementation overhead and requires developers who are specialized in security-related systems.

Chapter 5

Project Structure

This chapter aims to show the concrete structure of an project, which implements the previously discussed authentication mechanisms. The focus of this chapter is showing the effects of the different authentication mechanisms to the project itself. For the simplicity topics like authorization, key management and user context sharing are not handled in this chapter. The visualizations of this chapter are based on the backend of a flea market app.

5.1 Flea Market App

The flea market app is an Android App written in the programming language Kotlin. The main features are buying, renting and swapping items. The user is authenticated using firebase authentication. He has to present his access token to the Microsoft API Gateway with each request. The backend of the app is based on the microservice architecture. The microservice are mainly implemented in C# using the ASP.Net Core framework. Actually the backend contains the following services:

- AdService
- UserService
- ChatService
- MediaService
- SubscriptionService
- ReportService

Each service has its own PostgreSQL database. The services are hosted on Microsoft Azure using docker containers. Only the AdService and the UserService will be used to show an the communication within the deployment of the project using the discussed authentication mechanisms.

5.2 Structure

Figure 5.1 shows an extract of the previously described backend and visualizes the communication of the needed components. In this example the user fetches all ads which are in his surrounding. Therefore the AdService is used to retrieve the ads from

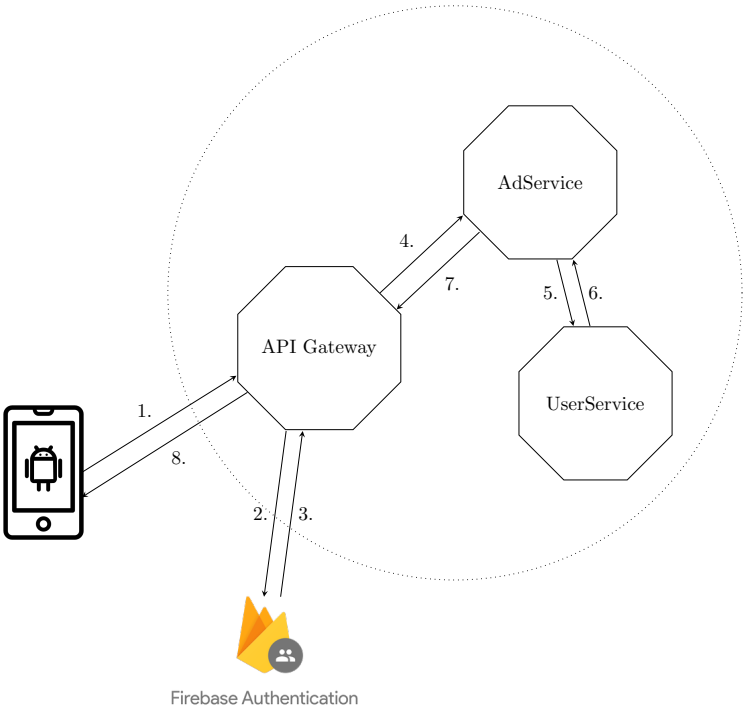

Figure 5.1: Communication among the components of the shown project

the database and the UserService is needed to preview information about the seller. In this use case the following components are necessary:

Android App: The Android App is the User Interface for the client to access the functionalities of the services. The requests sent by the Android App are sent in beyond of the user.

Firebase Authentication: The Firebase Authentication service is responsible for validating the access tokens wich are transferred by the users. The app also communicates with this service to get an access token, but this is done in an earlier stage.

API Gateway: The API Gateway is the only entry point into the deployment. Therefore the API Gateway is the only component which directly communicates to the Android App.

AdService: The AdService is responsible to manage all ads offered to the user of the app.

UserService: The AdService is the service which is responsible for managing the users.

5.2.1 Workflow using mTLS

1. The client sends an API request to the Microsoft API Gateway using the Android App. The communication between the API Gateway and the App is secured using HTTPS. Therefore the server is authenticated to the client using TLS. The client

is authenticated to the server by embedding an firebase access token within the Authorization header.

2. The API Gateway sends the received token to the Firebase Authentication service to validate it. This procedure is defined as a policy within the policy file of the API Gateway.
3. The Firebase Authentication service returns the information whether the persented token is valid or not.
4. When the client provided a valid access token, the request of the client is forwarded to the **AdService**. The communication between the API Gateway and the **AdService** is secured using mTLS. This means both parties have to present a certificate, signed by a trusted CA. Therefore the webserver of the **AdService** has to be configured to allow or even require Client Certificates.
5. After processing the request from the API Gateway the **AdService** sends a request to the **UserService** to retrieve the additional information about the owner. The communication between the **UserService** and the **AdService** is also protected using mTLS, so it has to be configured like the **AdService**. The certificate is appened to the request using a HTTPClient, which is injected to the Controller of the WebService using Dependency Injection.
6. When the **UserService** processed the request, it responds with the expected result. The response does not require to perform the authentication again, since TCP connection between the **AdService** and the **UserService** is still opened.
7. After the **AdService** processed the response from the **UserService**, it uses the opened connection with the API Gateway and transfers its response.
8. The API Gateway forwards the response from the **AdService** to the Android App. This connection is still secured using TLS and not mTLS. The App can now process the response and present the requested information to the user.

5.2.2 Workflow using JWT

The workflow using JWT and the workflow using mTLS are very similar, therefore only the steps which differ between the mechanisms are described again.

4. The request from the client is forwarded to the **UserService**. Therefore the API Gateway has to create a valid JWT to communicate with the **UserService**. On the Microsoft API Gateway, the logic to create a JWT is implemented as a policy. The JWT, which is signed using the private key of the API Gateway is transferred within the Authorization header.
5. The **AdService** has to retrieve additional information from the **UserService**. Now the **AdService** has to present his JWT to the **UserService**. This is done by using a HTTPClientFactory, which automatically embeds the signed JWT within the Authorization header, when the request is sent. If the **AdService** does not know the certificate of the **UserService**, it will deny the request and ask the **AdService** to present its certificate. In this case the request is repeated and the certificate of the **AdService** is transferred during the TLS handshake, like it would be transferred using mTLS.

5.3 Implementation Details

5.3.1 mTLS

As already discussed in chapter 4, the implementation of mutual TLS does not require very much logic on the service-side. The best way to implement mTLS, in a ASP.Net Core API is using the **Microsoft.AspNetCore.Authentication.Certificate** library. It provides the mechanism to add certificate authentication as **AuthenticationScheme** and implement custom **CertificateAuthenticationEvents**. The **CertificateAuthorityService**, implements the interface **ICertificateAuthorityService** which is shown in listing 5.1. It provides features to manage a custom certificate truststore and validate certificates using this truststore. An instance of the **CertificateAuthorityService** is injected to the **CertificateAuthenticationEvents**. The depenendency injection is managed by the **Microsoft.Extensions.DependencyInjection** library. The **UseAuthentication** and **UseAuthorization** functions of the **ApplicationBuilder** have to be called to use the created **AuthenticationScheme**. The functions of the API Controllers have to be marked with the [**Authorize**] annotation, to require the client to be authenticated to consume the function. Therefore it is possible to exclude some functionalities from the certificate authentication.

The client side does not require much logic either. The client has to attach his certificate to the request. In ASP.Net this is done, by creating a custom **HTTPHandler**, and setting the **ClientCertificate** property. The **HTTPHandler** is then used to create a **HTTPClient**, which is used to perform the requests. It is good practise to create the **HTTPClient** once and then inject it into the Controllers using dependency injection. This helps improving the performance and especially prevents, that the certificate of the service has to be parsed multiple times.

```
1     public interface ICertificateAuthorityService {
2       public void AppendCertificate(X509Certificate2 certificate);
3       public bool ValidateCertificate(X509Certificate2 certificate);
4     }
5
```

Listing 5.1: ICertificateAuthorityService interface, which is implemented by the injected CertificateAuthorityService

5.3.2 JWT

The best way to implement the authentication using self-signed JWTs in ASP.Net Core is a custom middleware. A custom middleware provides the possibility to perform actions on the receiving request before, they are handled by the API Controllers. The **JWTAuthenticationMiddleware** validates the JWT and the certificates of all received request. The validation is performed like it is shown in 5.1. When a client certificate is transferred within the TLS handshake, it is checked using a service that implements the **ICertificateAuthorityService**, which was shown in listing 5.1. If the certificate is valid, it is mapped to the issuer of the certificate within a custom truststore of the **JWTValidationService**. The **JWTValidationService** implements the **ITokenValidationService** interface which is shown in listing 5.2. Both the **CertificateAuthor-**

eyJhbGciOiJSUzI1NiIsImtpZCI6IkYwMURFNTBCNTU5MzVBQ0VEOUNDNzdCRjRFMjY5NkVDOTE4MUI5NjkiLCJ0eXAiOiJKV1QifQ. eyJuYmYiOjE2NDU1MjU5MjMsImV4cCI6MTY0NTUyNjIyMywiaXNzIjoic2VydmljZTEuc3dhcGluZG8uY29tIiwiYXVkIjoic2VydmljZTIuc3dhcGluZG8uY29tIn0.


```
{
        "alg": "RS256",
        "kid": "F01DE50B55935ACED9CC77BF4E2696EC9181B969",
        "typ": "JWT"
}
{
        "nbf": 1645525923,
        "exp": 1645526223,
        "iss": "service1.swapindo.com",
        "aud": "service2.swapindo.com"
}
```


Figure 5.2: Header and Payload of a JWT, created by the JWTCreatorService

ityService and the **JWTValidationService** are injected into the **Invoke** function of the **JWTAuthenticationMiddleware** using dependecy injection.

```
1     public interface ITokenValidationService {
2       public bool PutIntoTruststore(X509Certificate2 certificate);
3       public bool ContainsIssuerInTruststore(String issuer);
4       public bool ValidateTokenWithTruststore(String token, string issuer);
5       public bool ValidateTokenWithTruststore(String token);
6     }
7
```

Listing 5.2: ITokenValidationService interface, which is implemented by the injected JWTValidationService

The client has to implement the logic for creating JWTs and attaching them to the requests within the Authorization header. The JWTs are created, using the **JWTCreatorService** that implements the **ITokenCreatorService** which is shown in 5.3. The **JWTCreatorService** and a **HTTPClient** are injected to the API Controllers using dependency injection. The Controllers can choose between two clients, one that contains the certifcte of the service and one that does not contain any additional data. In both cases the Controller has to use the **JWTCreatorService** to create a JWT and append it to the Authorization header of each request. An authentication JWT, which is created using the **JWTCreatorService** is shown in figure 5.2.

```
1     public interface ITokenCreatorService {
2       public string CreateToken(string audience);
3     }
4
```

Listing 5.3: ITokenCreatorService interface, which is injected to the API Controllers

Algorithm 5.1: Pseudocode of the request validation using self-signed JWTs

```
certificate ← request.Connection.ClientCertificate
token ← request.Headers[Authorization]
missingCertificate ← false
if token is null then
    response.StatusCode ← 403Forbidden
    authenticated ← false
else
    issuer ← null
    if certificate is not null then
        if certificate is trusted then
            if putCertificateIntoTruststore(certificate) is successful then
                issuer ← certificate.subject
    else
        if containsIssuerInTruststore(token.issuer) then
            issuer ← token.issuer
        else
            missingCertificate ← true
    if issuer is not null && validateJWT(token) is valid then
        authenticated ← true
    else
        if missingCertificate is true then
            response.StatusCode ← 401Unauthorized
        else
            response.StatusCode ← 403Forbidden
        authenticated ← false
```

5.4 Conclusion

This chapter showed an concrete project which implements the previously discussed authentication concepts. Furthermore, some details were shown to give an idea how the concepts can be implemented. The implementation details also prooved that the authentication mechanism using self-sigend JWTs requires more code than the implementation using mTLS. The aim of this implementation was to clarify, what the services have to do when they send and receive requests and responses. The concrete implementation differs between the used programming language and the used technologies.

Chapter 6

Experiment

This chapter discusses an experiment, which compares the performance of the previously described authentication mechanisms. Even if the performance is not the major decision point to choose the correct authentication mechanism, it is still worth considering it. Especially, because the migration from a monolithic architecture to the microservice architecture already results in a massive performance decrease of around 79.1% [18]. Therefore the performance is already restricted, and the authentication mechanisms should not produce too much overhead.

6.1 Experiment Setup

The setup consists of two components, the service, that responds to requests and the client, which performs requests and measures the taken time. Both components are located in the same network and run on the same machine. The service is developed in C# using ASP.Net Core, same as the services of the flea market app, mentioned in chapter 5. The client is a console application, developed in C# using .NET. It is not a microservice, but it acts as a service that is located within the deployment. In a usual deployment it is not good practice to access the services directly from an external application, bypassing the API Gateway. Nevertheless, for the purpose of an experiment, this is allowed to make the setup simpler and reduce falsifications by other components.

The experiment simulates the situation that a service (the console application) performs 1000 requests to another service. The connection between the client and the server has to be established, when the first request is performed. Therefore the first request will take significantly longer, since the full TCP handshake and TLS handshake have to be performed. The other request can reuse the already created connection and do not have to perform the whole initialisation process again. The tests were performed five times to minimize distortions between the test runs.

The console application tracks the whole time, which is needed to perform a request not only the time needed by the service to respond. This experiment does not aim to give and approximation of the expected request durations with the declared technology stack. Instead it will compare the trends between the authentication mechanisms. The exact durations are not relevant, since they are influenced by many factors, like the hardware of the server and the client.

Two different implementations of the approach using self-signed JWTs are demonstrated. First, an implementation of the self-signed JWT approach, in which a new JWT is created for each request is shown. The second implementation uses the same JWT for all requests. This should give an idea how the performance using self-signed JWTs can be improved by efficiently reusing the tokens. Furthermore the experiment includes the response duration without using any authentication mechanism. This should show how much time is accounted for the authentication mechanisms and how much time is accounted for other tasks like the transport of the request or the calculation of the random number.

6.2 Experimental Results

Authentication Mechanism	**Average Request Duration**	
	first connection	reuse connection
mTLS	199.66 ms	10.18 ms
self-signed JWT	226.83 ms	15.38 ms
self-signed JWT (reusing token)	216.1 ms	8.75 ms

Table 6.1: Average request durations of the authentication mechanisms, when random numbers are fetched

The results of the experiment are shown in table 6.1. As already expected, the approach using no authentication mechanism is the most efficient approach. The first request takes only ... ms in average and the following requests take only 1... ms in average. Since the authentication is performed only once per request it is not valid to say that for example the request duration increases by 1018% when mTLS is used. The percentual value is only so significant because the task of generating a random number is very simple. Therefore for this case only the time offsets are interesting. It shows that the approach using mTLS increases the request duration by about 8ms per request.

The lowest duration for the first connection is achieved using mTLS. This is reasonable, since the authentication using self-signed JWTs exchanges the certificate of the client in the first request using the extended TLS handshake same as mTLS. Therefore in all three cases the extended TLS handshake has to be performed but the JWT approaches have to attach the JWT additionally. The approach that reuses a previously created JWT needs about 10 ms less than the approach in which an new JWT has to be created. The first connection using an already created JWT takes still around 16 ms more than the first connection using mTLS. This time overhead is caused by the logic that checks the certificate and stores it into the truststore and then checks the validity of the JWT.

The approach using-self signed JWTs with already created tokens is the most efficient approach that focusing on the requests after the first connection. Each request takes about 9.7 ms which is about 1.5 ms less than using mTLS. Nevertheless, the service has to create a new token in some situations. Therefore both approaches would have about the same average request durations. The approach, creating a new JWT for each

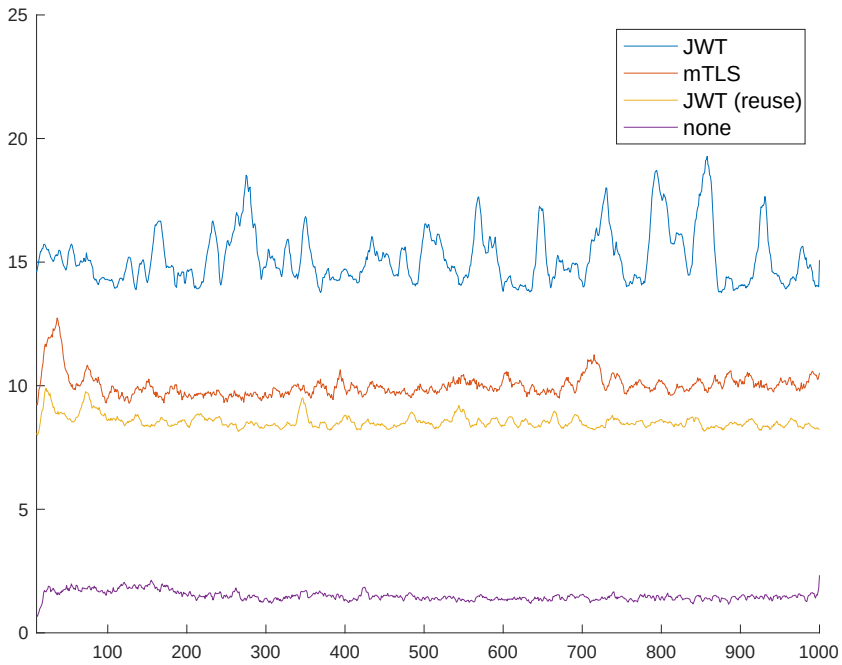

Figure 6.1: Trend of the request duration of the compared approaches excluding the first request

request has the worst performance. This shows that the JWT creation takes around 6.5 ms per token in average.

The trend between the request durations is additionally visualized in figure 6.1. It shows that the all approaches have a very stable duration timespan except the approach creating a new JWT for each request.

Chapter 7

Final Remarks

7.1 Discussion

This thesis explained and compared two authentication mechanisms for the service-to-service security in a microservice deployment. Both mechanisms are based on public key cryptography, but each mechanism has its own advantages and disadvantages.

Mutual TLS is a very efficient and straightforward authentication mechanism. The implementation of mTLS is very simple, since the work is handled by the TLS protocol. mTLS does not provide many configuration parameters and it does not allow to add custom functionalities, like sharing the user context without another technology. Nevertheless if an developer aims to implement only service-to-service authentication, mTLS is the superior authentication mechanism.

As soon as nonrepudiation is an requirement self signd JWTs are the superior authentication mechanism. Furthermore JWTs make the identity propagation more convenient and allow the developers to customize the authentication mechanism and add additional parameters. On the other hand the implementation of self-signed JWTs is more challenging and requires each service to know how to work with JWTs. Therefore choosing JWTs over mTLS would be unnecessary overhead when the target is implementing only service-to-service authentication. The decision if the additional control of the approach using self-signed JWTs is worth the overhead has to be evaluated for each project independently.

The biggest challenge of both authentication mechanisms is the key-management. Both mechanisms require a PKI and require to handle all associated key management tasks. Therefore the implementation of the authentication mechanisms is much less work than the key management. Nevertheless, the level of security that is provided using public key cryptography, is worth the expenses.

7.2 Summary

Service-to-service authentication is a requirement caused by the migration to the microservice architecture. The function calls within the monolithic backend migrate to remote calls. The remote calls have to assure authentication, confidentiality and integrity. Confidentiality and integrity can be assured using TLS, but authentication of

both parties requires additional mechanisms.

This thesis compared two of the most pupular authentication mechanisms for service-to-service authentication. Therefore the fundamentals of both mechanisms were discussed and the concepts of the two authentication mechanisms were described in detail. Additionally an project that implements the authentication mechanisms was reviewed and a experiment that should give an assumption about the performance overhead of the authentication mechanisms was performed and interpreted.

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