Distributed Systems Security

CSE 486/586: Distributed Systems

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Distributed Systems Security

We have ignored a lot of security up to this point.

This is because:

- Systems security is very hard
- UB offers entire courses on security
- Some background in cryptography and cryptographic protocols is necessary for a thorough treatment

In this lecture, we will:

- touch on some important security considerations
- explore some distributed security protocols

Disclaimer Redux

This lecture is not a replacement for a more thorough treatment of security.

This lecture is greatly (over?)simplified for time reasons.

This material is to give you a place to get started.

Applying Security

Like *almost everything we talk about*, security in distributed systems depends on your application.

It is important to:

1. Define your threat model (remember elections?)
2. Design a security model to meet the threats
3. Select mechanisms and protocols to implement your model
4. Demonstrate (ideally *prove*) that your implementation captures the models

Threat Model

You must know what you are trying to secure and what the threats against it are, before you can secure it.

You define:

- What am I trying to protect?
- How are those things vulnerable?
- *etc.*

E.g., you might define:

- authentication credentials as an asset to protect
- the authentication database server as a vulnerable interface to that data

Full threat modeling is out of scope for this course!

Cryptography

Distributed security solutions must often deal with

- Varying levels of trust within the system
- Multiple authorities
- Untrusted infrastructure
- *etc.*

These features make encryption, and in particular public key cryptography, an important part of distributed security.

Threats

Threats can be divided into several categories. One division is:

- Information Disclosure: An attacker acquires information that was intended to remain private or controlled.
- Unauthorized Access: An attacker obtains access to a system or facility without appropriate permission.
- Denial of Service: An attacker prevents legitimate users of a service from accessing it normally.

There are many threat taxonomies, and this division may not cleanly capture all possible threats for all systems.

Vulnerability

A vulnerability is a property of an implemented system which allows exploitation of a threat.

Examples:

- A network protocol may expose an information disclosure threat by failing to encrypt data or using an encryption protocol inappropriately.
- An authentication service may expose an unauthorized access threat by allowing an authentication token to be re-used.
- A web service may expose a denial of service threat by providing an computation-heavy feature to un-authenticated users.

Threat Interplay

One vulnerability can lead to another vulnerability.

E.g.:

- An authentication system has an information disclosure vulnerability
- Leaked credentials lead to unauthorized access

In a distributed system, this can mean that a vulnerability in a system administered somewhere else may lead to threat exploitation in a local system.

There are techniques to mitigate this, such as the principle of least authority.

Principle of Least Authority

The principle of least authority states that a user or system should have the minimum access required to accomplish their tasks.

Some common techniques to accomplish this are:

- Role-based access control
- Capability-based security
- Privilege separation

Some systems applying this principle:

- Tahoe-LAFS
- EROS: The Extremely Reliable Operating System
- Microsoft Azure

Cryptography

Cryptography gives us tools to:

- Encrypt data so that it cannot be viewed by third parties
- Agree on a secret to be used for encryption
- Sign data so that its authenticity can be verified
- …

In distributed systems, cryptography allows systems to communicate safely and securely over untrusted networks.

Terminology

Some basic terminology (dangerously vague and sloppy!):

Cryptographic protocol: A series of steps between to be performed between two or more parties to accomplish some cryptographic goal.

Key: A value used in a cryptographic function which determines its output, and is difficult or impossible to deduce from its other inputs and outputs.

Shared-key (symmetric) encryption: Two parties share a secret and use that secret to encrypt.

Examples: AES, Blowfish, ChaCha20

Public-key (asymmetric) encryption: One party has a secret key, and shares a related value (the public key) with any other parties. Data encrypted with one key can be decrypted by the other.

Examples: RSA, ElGamal, ECC

Message digest (hash): A data item is passed through a one-way function, producing a value that is dependent on the input data but from which it is difficult or impossible to predict properties of the input.

Examples: SHA-256, SHA-3 (Keccak), BLAKE2/3

Message authentication code (MAC): A small datum that can be used to verify the authenticity of another, possibly (much) larger, message.

An HMAC is a MAC constructed using a hash function and a secret key.

Common Cryptographic Tools

TLS, or Transport Layer Security (formerly SSL):
A standardized suite of cryptographic protocols used to secure streaming communication channels, such as TCP sockets. (TLS can also be used for datagrams.)

scrypt:
A method of creating a key from a password. Scrypt is designed to make brute-force password retrieval from the key, or password guessing to find a key, arbitrarily difficult.

Kerberos:
A distributed authentication protocol using shared key cryptography.

TLS

TLS [2] is an improvement on SSL.

- SSL was developed by Netscape in the mid 1990s.
- SSL provides:
  - authentication of the server
  - optional authentication of the client
  - protection against eavesdropping and man-in-the-middle attacks
- Early versions of SSL were rife with security flaws.
- TLS succeeded SSL, with TLS version 1.3 being current.
- TLS 1.2 is still in wide usage.

TLS Authentication

TLS authenticates hosts via public key encryption.

Servers have a private key with its corresponding public key signed by a Certificate Authority (CA).

Certificate authorities sign server keys and issue a certificate containing this signature.

- (We won't get into the details of signatures.)

Clients agree to trust certain CAs to issue certificates.

TLS Properties

A stream protected by TLS provides:

- Proof of the server's identity, if the CA is trusted.
- Assurance that the data in the stream is un-tampered-with.
- Protection of the data in the stream from eavesdropping.

TLS supports many ciphers, hashes, and cryptographic protocols.

TLS stream negotiation (handshaking) is expensive and slow. (Several RTT; TLS 1.3 improves on this.)

Kerberos

Kerberos [3] is an authentication and key distribution protocol from MIT's Project Athena.

Project Athena also spawned the X Window System and is the source of the popular "MIT license" for open source software.

Kerberos handles:

- Authenticating a user to a server
- Distributing encryption keys for secure communication

Kerberos uses only symmetric-key cryptography.

Kerberos Architecture

The Kerberos server is a Key Distribution Center (KDC).

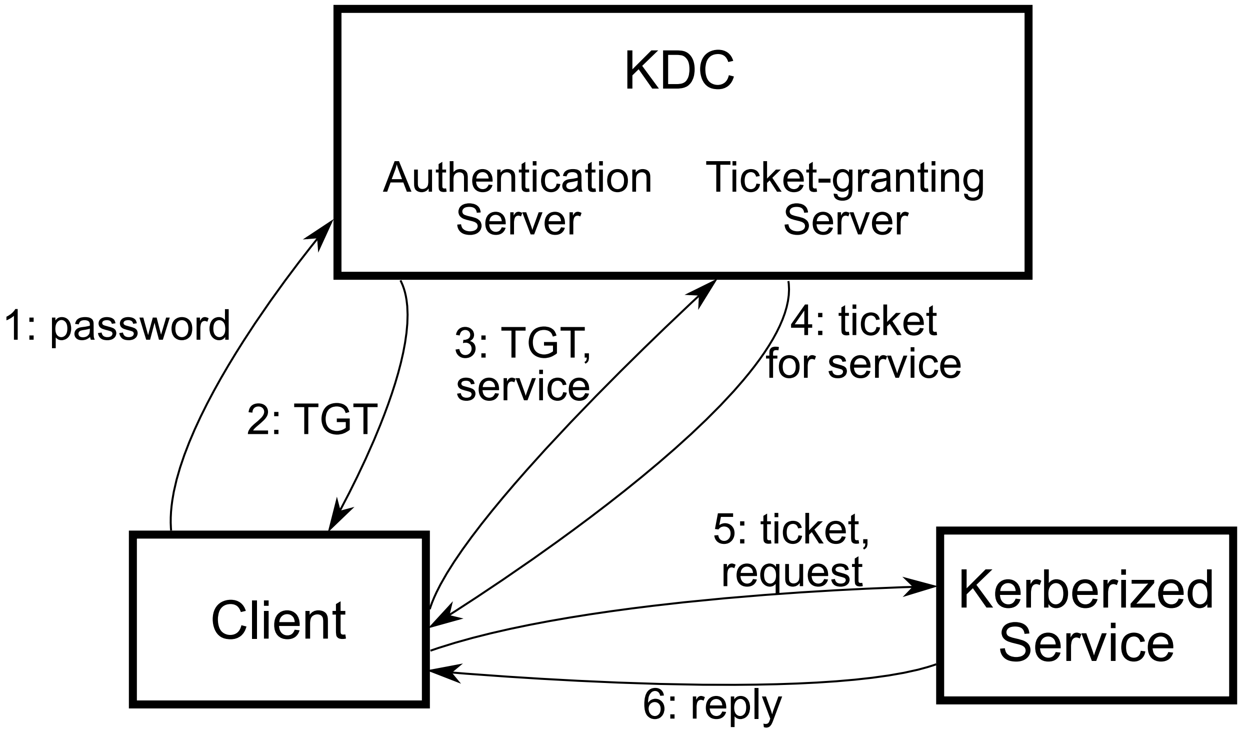
Clients authenticate with an authentication service on the KDC using a password from which an encryption key is derived.

The KDC issues a ticket-granting ticket (TGT) to clients upon authentication.

Services supporting Kerberos accept tickets from a ticket-granting server (TGS) on the KDC as proof of identity.

Clients use their TGT to request tickets for services from the TGS.

Kerberos Architecture



Trust and Secret Keys

The only trusted entity in Kerberos is the KDC.

Neither clients nor servers must be trusted.

The KDC shares secret keys with every client and server.

- Client keys are derived from user passwords.
- Server keys are registered with the KDC.

The shared keys are used only to authenticate and exchange session keys.

Tickets

Kerberos is built around tickets, which are encrypted with the server key for the service they grant.

Tickets are time-limited, having a validity start time and end time.

Tickets contain:

- A client ID C
- A server ID S
- The begin time
- The end time
- A shared session key for C and S

Communication can be encrypted with the session key.

Mechanisms: Client Authentication

To acquire a TGT, the user sends a request containing a nonce to the authentication server.

The authentication server replies with a TGS session key and the nonce, both encrypted to the client key (user password), as well as a TGT.

- Decrypting the session key proves the client knows the password.
- Returning the nonce proves the server knows the password.
- Thus two-way authentication is achieved.

The session key and TGT will be used for communication with the TGS.

Mechanisms: Service Requests

When the client wants to connect to a Kerberized service, it contacts the TGS and asks for a service ticket for that service.

The request is encrypted by the session key and includes the TGT and a nonce.

The TGS replies with a service session key and the nonce, both encrypted with the TGS session key, as well as a service ticket.

- Similar to the authentication server exchange, mutual decryption proves identities.
- The service ticket is encrypted to the server.

Mechanisms: Service Authentication

The client presents a ticket to a server along with a service request.

The server decrypts the ticket, then verifies its timestamps and the client identity.

The server's reply is encrypted with the session key in the ticket.

- This ensures that only the authorized client can decrypt it.
- A third time, mutual decryption proves identities.

Summary

- Distributed security is very hard, and approaches depend on the application.
- The principle of least authority can be used to separate concerns and minimize collateral damage from vulnerabilities.
- Cryptography is important when infrastructure is untrusted.
- TLS is used to protect socket communications.
- Kerberos is a distributed authentication and key exchange protocol that requires minimal trust between entities.

Bibliography

Required Readings

[1] Ajay D. Kshemkalyani and Mukesh Singhal. *Distributed Computing: Principles, Algorithms, and Systems*. Chapter 16: 16.3.7, 16.4.4. Cambridge University Press, 2008.

Optional Readings

[2] Eric Rescorla. The Transport Layer Security (TLS) Protocol Version 1.3. RFC 8446. no date.

[3] B. Clifford Neuman and Theodore Ts'o. "Kerberos: An Authentication Service for Computer Networks". In: *IEEE Communications Magazine* 32.9 (September 1994), pages 33–38.