

Kerberos Protocol

Software Security

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Objectives of today's lecture

- Understanding how the *Kerberos* protocol works
- Being able to apply important *design criteria* for building security protocols
- Getting to know different *weaknesses of Kerberos* and countermeasures to increase the security level

Kerberos Protocol

– Motivation and Introduction –

Kerberos: The Dog of Hades

- Kerberos is a character from the Greek mythology
- Monstrous multi-headed dog that guards the entrance of the underworld to prevent the dead from leaving
- The parable is only partially applicable because the **protocol ensures that unauthorized users do not gain access to network resources**



Why to use a Kerberos protocol?

Motivation

- Protecting resources from unauthorized access
- *Each network connection* can be potentially insecure
- Network connections should not only be protected outside a subnet, but also within a subnet

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Problem

- Protection mechanisms based only on passwords are **not practical** for all **network connections**, e.g. if each contact between a user and a server requires entering a password
- ➔ Instead, a centralized key management should be introduced, supported by a secure protocol

What was the motivation for introducing the Kerberos protocol?
Which concepts are used to avoid the frequent request for
passwords during operation?

Which features should Kerberos offer?

Requirements

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- Optionally, *confidentiality and integrity* of communication data should be supported (note Kerberos originally only supported authentication)

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- The explicit intention is to prevent attacks by fake identities (*man-in-the-middle attack*)
- Other attacks, e.g. based on retransmitting old messages (*replay attack*) should be mitigated by the protocol design

What are the differences between Kerberos and Needham-Schroeder protocol? What are the common features?

General Remarks and History of Kerberos

Development of the MIT

- *Massachusetts Institute of Technology* (MIT) located in USA,
Development as part of the Athena project (1983-1991)
- Authentication service based on the symmetric variant of
the Needham-Schroeder protocol
- Versions 1 to 3 were only used internally at MIT

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Standardization

- Started with version 4 and MIT, IBM and DEC were involved
- In 1993 accepted as an international standard (RFC1510)
- Last detailed protocol update was in 2005 (RFC4120)
- Versions 4 & 5 are public, but v4 should no longer be used

Kerberos in Practice

Implementations

- Reference implementations from MIT for v4 and v5 (KRB5)
- Heimdal of KTS (*Royal Institute of Technology in Sweden*)
- Microsoft's version of Kerberos, used for Microsoft Active Directory from Windows 2000
- ShiShi, GNU GPL (*General Public License*)

Kerberos in Practice

Implementations

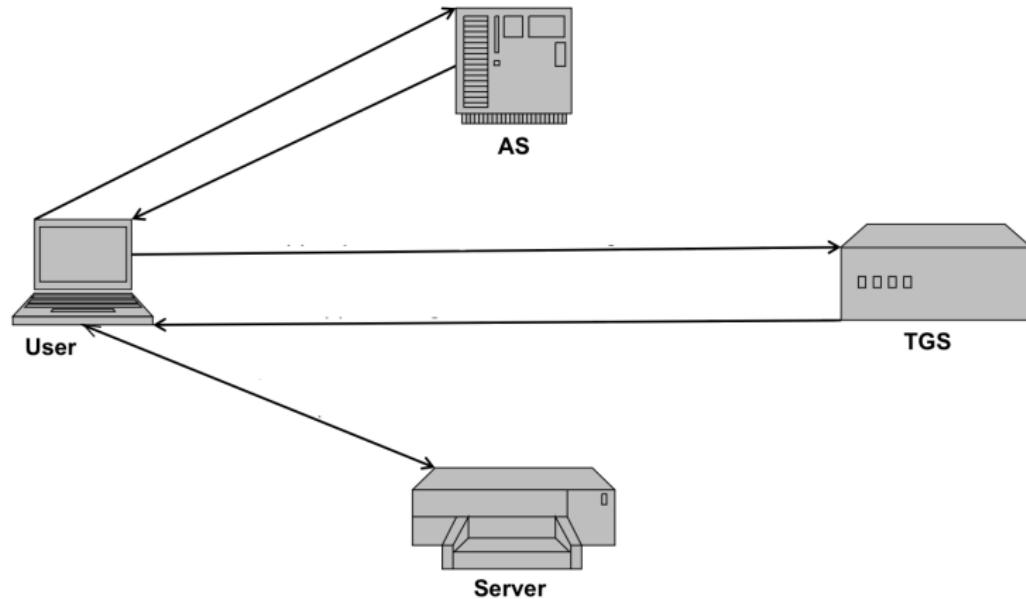
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Services that support Kerberos

- Secure Shell (ssh)
- Remote Shell (rsh, rlogin), Telnet
- Distributed file system (NFS, AFS)
- Email services

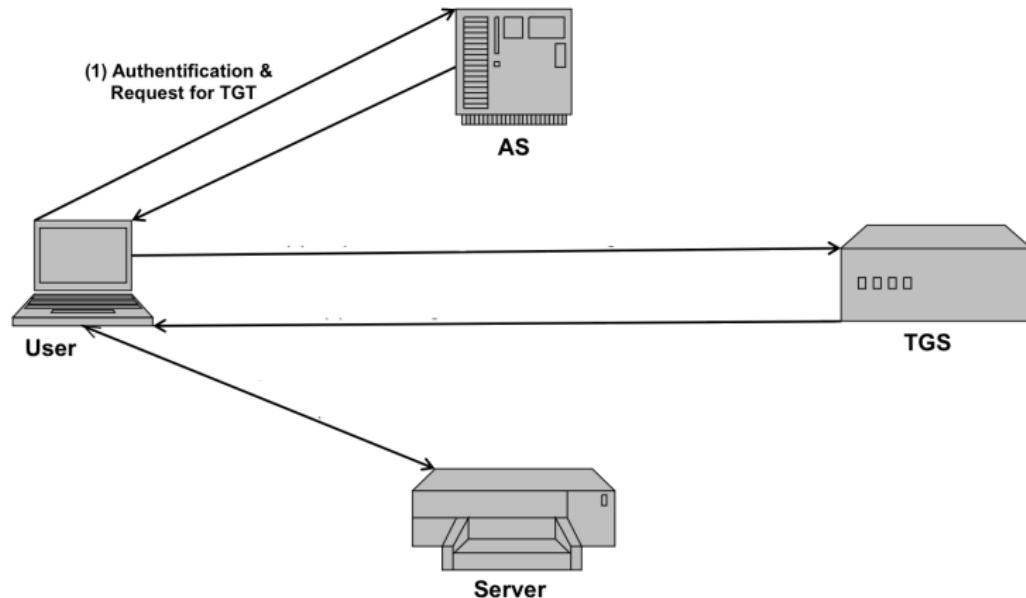
The Kerberos Protocol

Overview of the Kerberos Protocol



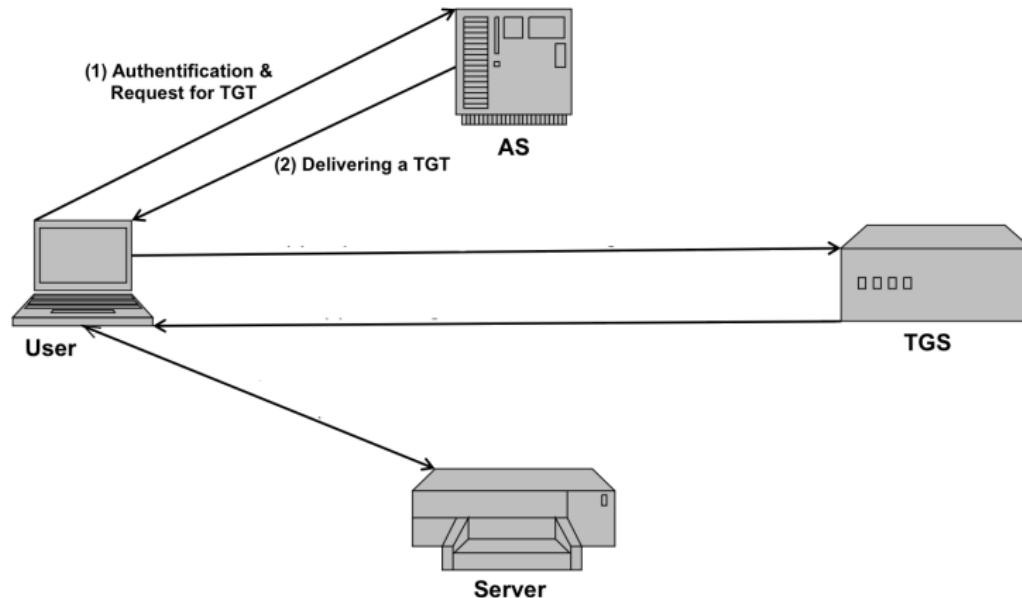
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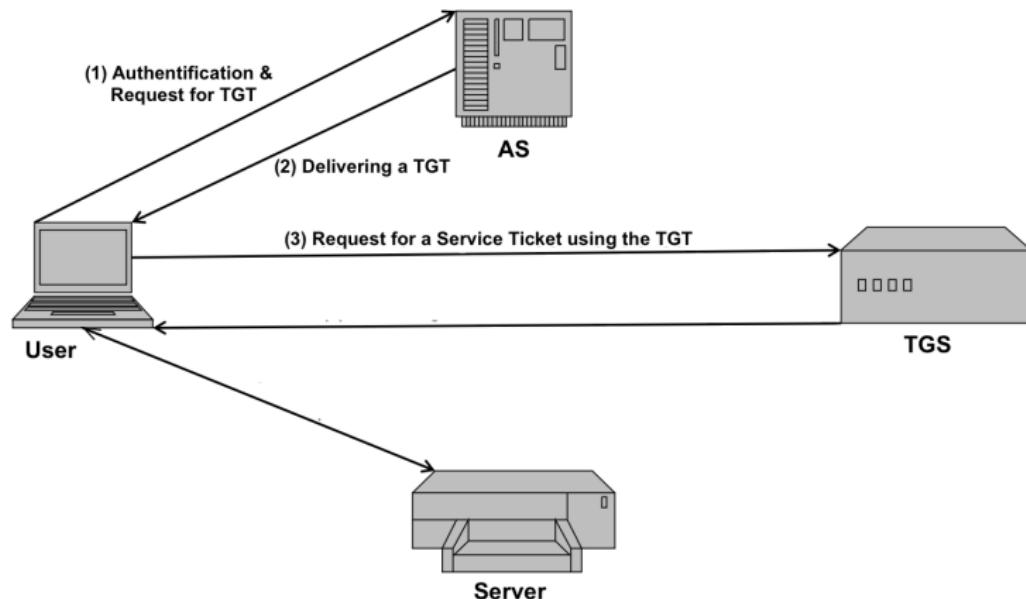
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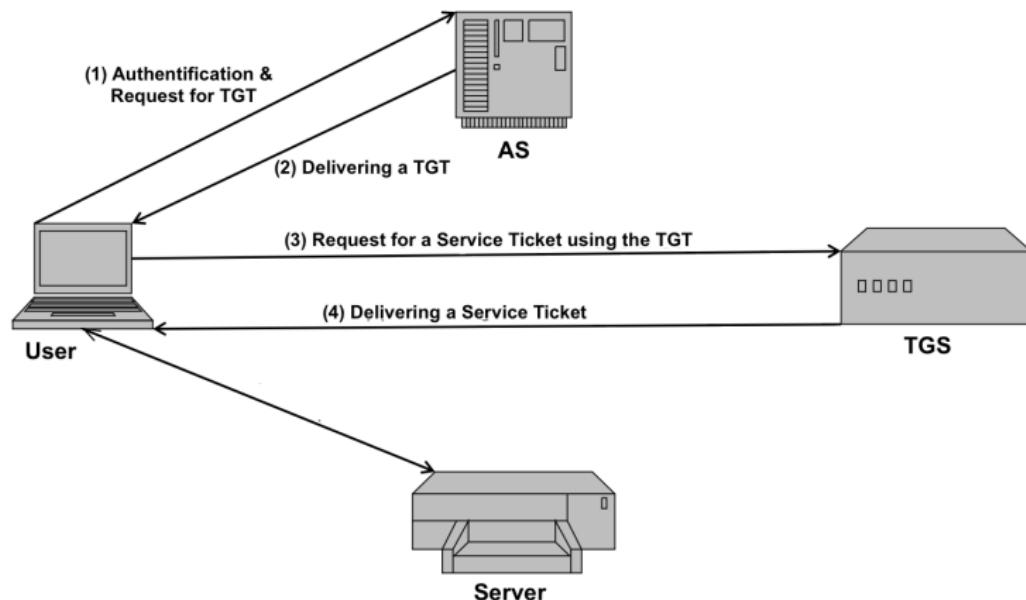
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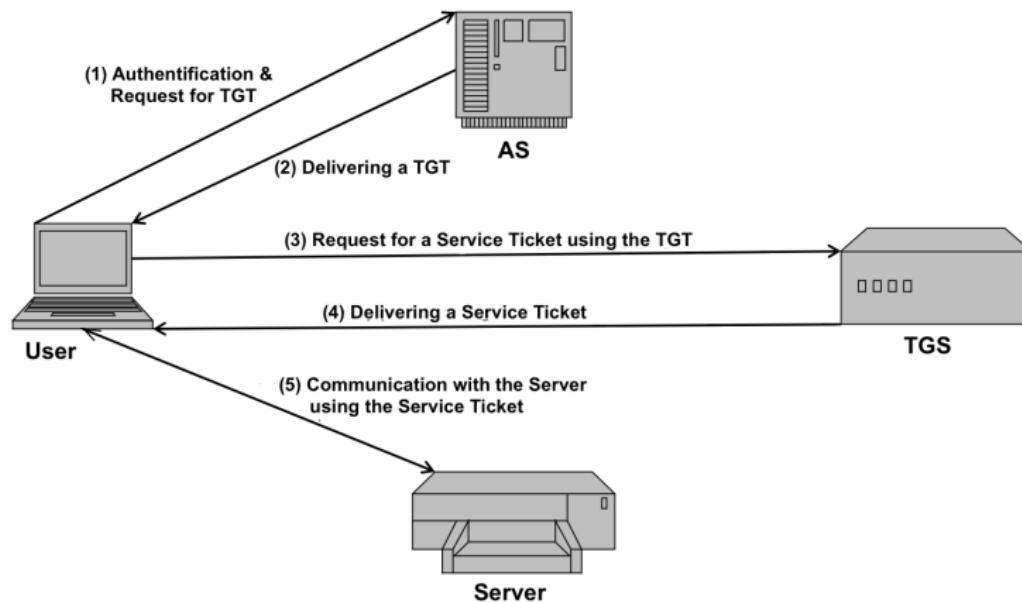
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Server Infrastructure

Authentication Server (AS)

- Authenticates clients (*Principals*) based on passwords and is able to generate tickets for the TGS

Ticket-Granting Server (TGS)

- Authenticates clients based on submitted tickets (issued by AS) and creates service tickets for requested servers

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Key-Distribution Center (KDC)

- Provides all necessary services for Kerberos
- Services of AS/TGS are often on *the same* server deployed

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Key-Distribution Center (KDC)

- Provides all necessary services for Kerberos
- Services of AS/TGS are often on the same server deployed

→ Assumption: Services of the KDC are trustworthy
(*Trusted Third Party*)

Credentials

Ticket-Granting Ticket (TGT)

- Ticket is issued by AS
- Using this ticket client can request service tickets at TGS

Service Ticket

- Ticket is issued by TGS
- Using this ticket client is able to request services at ordinary servers and to use their resources (e.g. print services)

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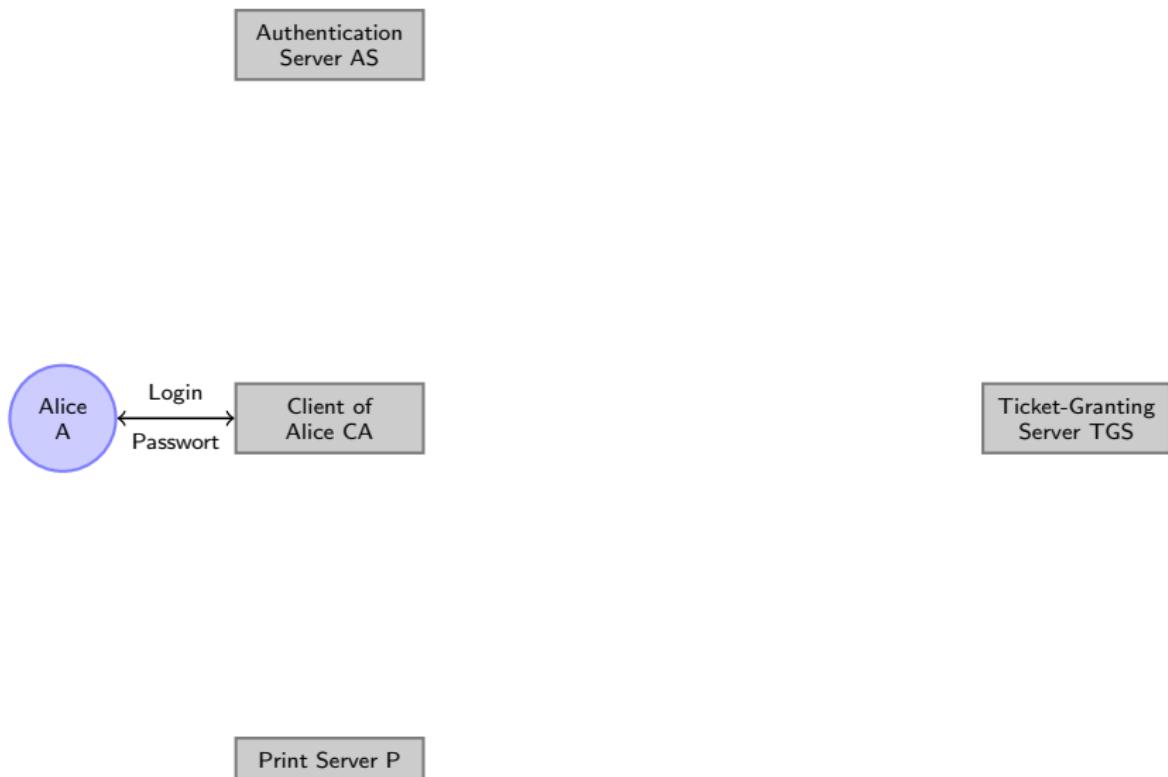
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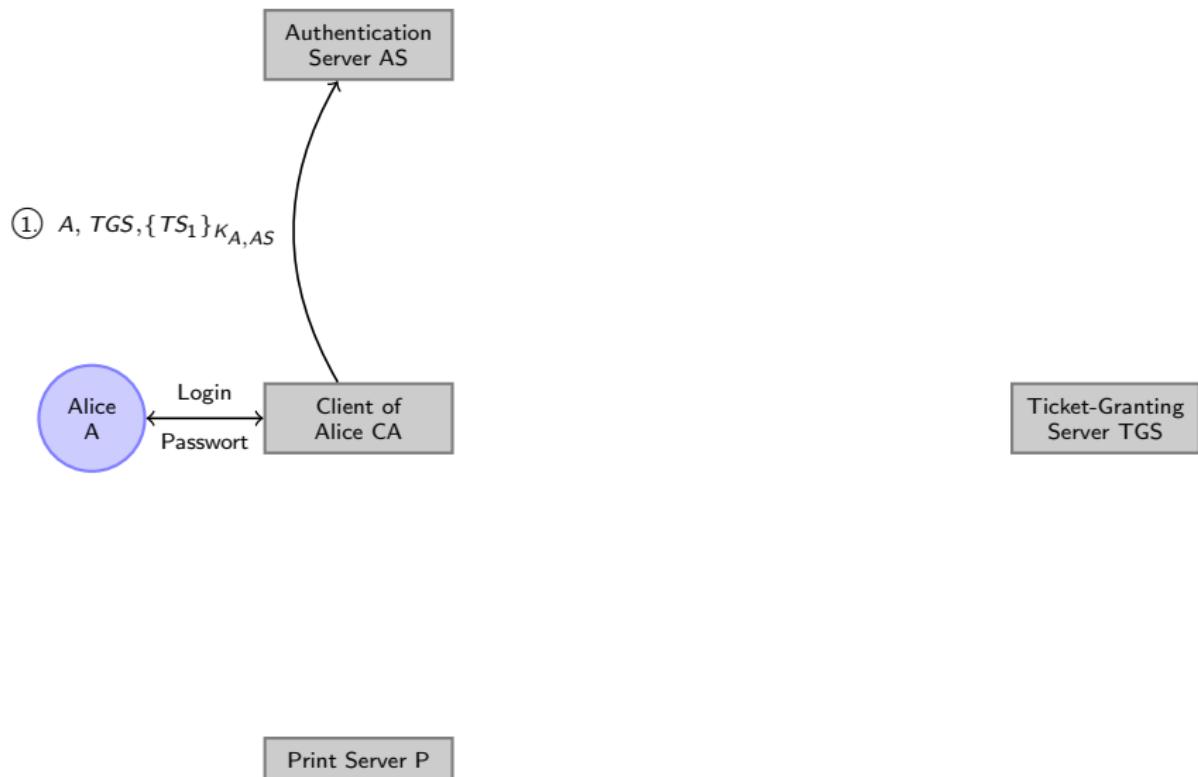
Authenticator

- For verification of authenticity of principals
- Must be shown to both ordinary servers and the TGS

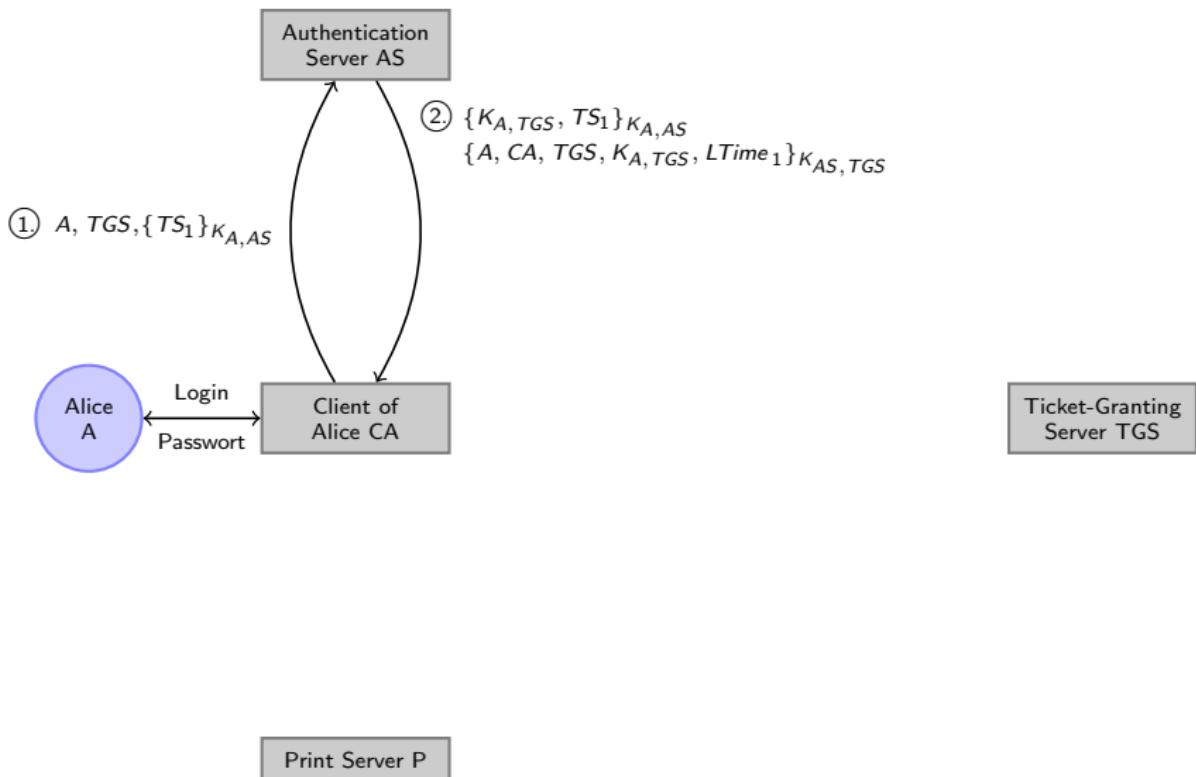
Protocol Steps for Kerberos



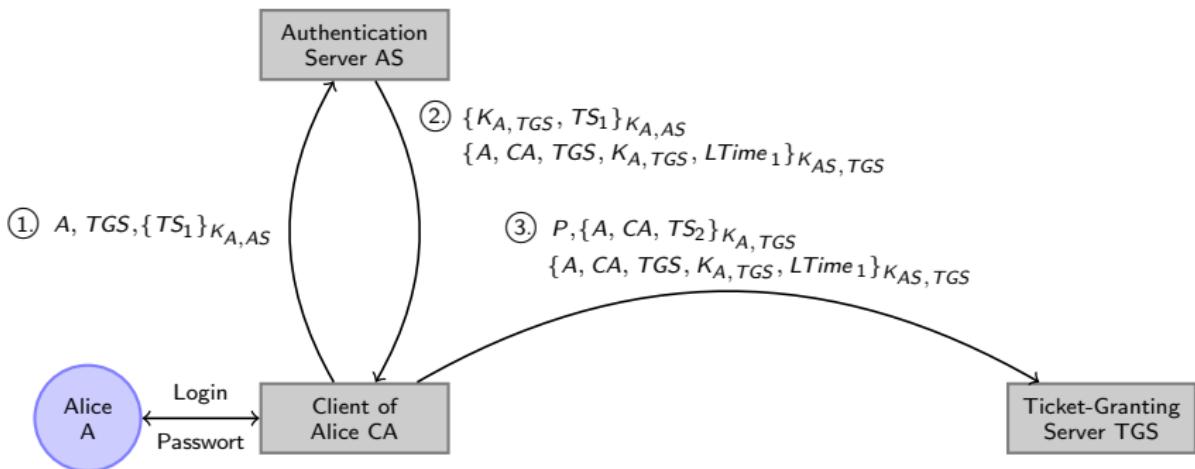
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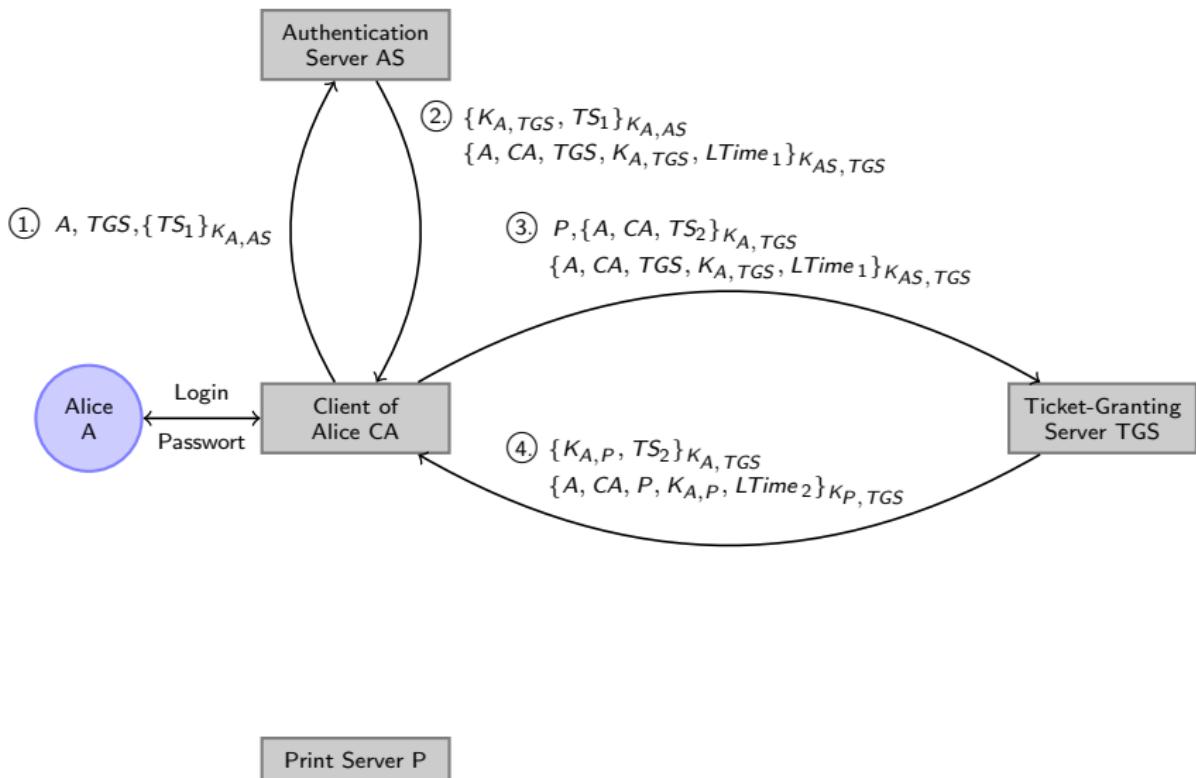


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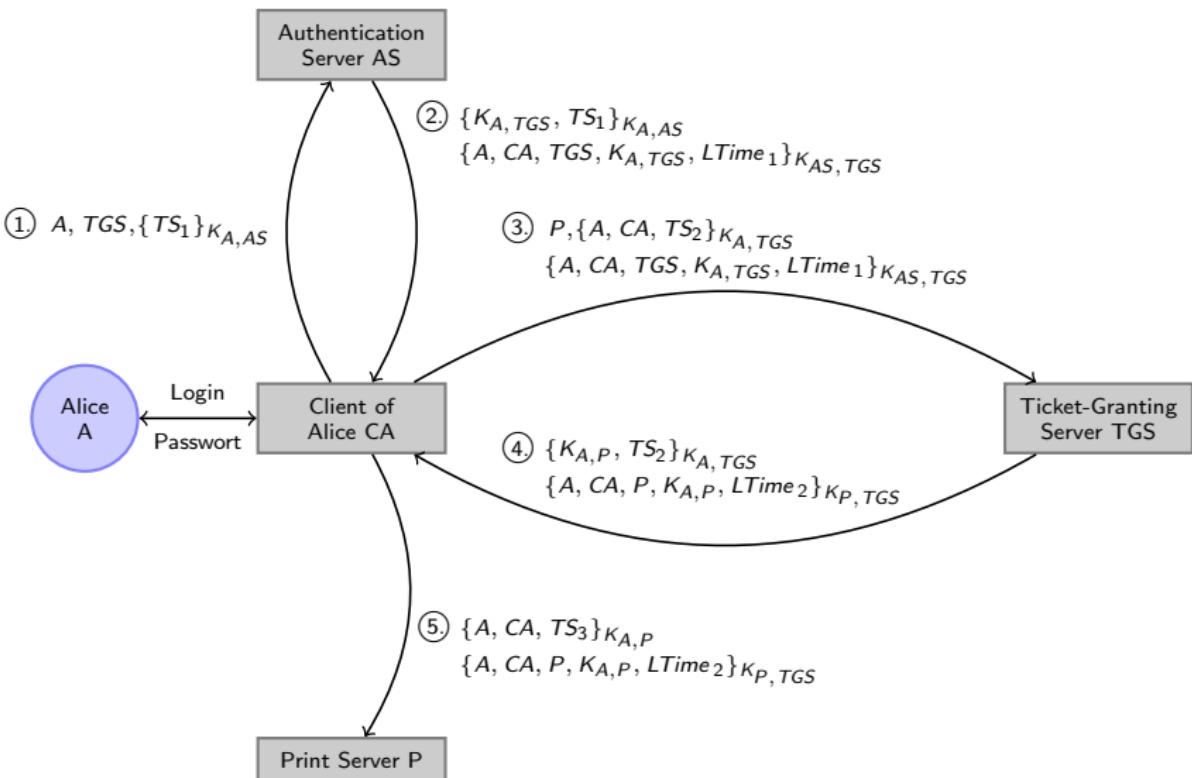


Print Server P

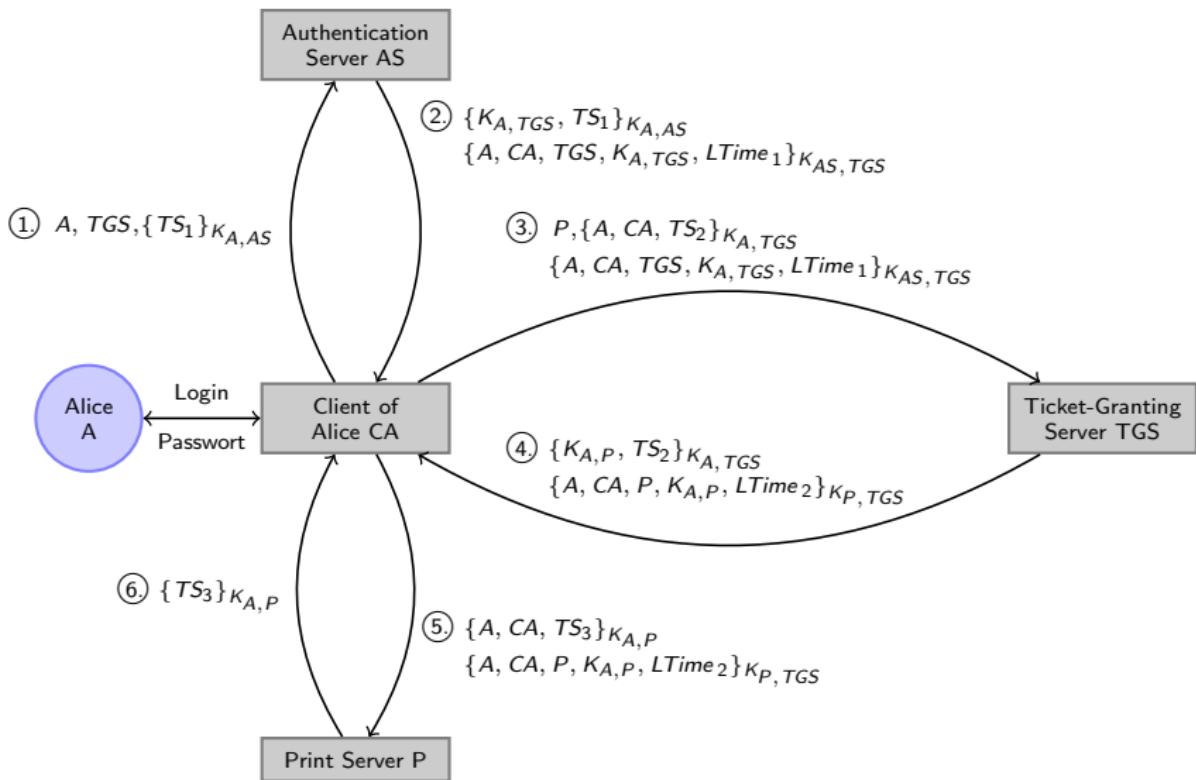
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Protocol Steps for Kerberos



Weaknesses of the Kerberos Protocol

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Weak Points for Attacks

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Weak Points for Attacks

- 1 Key management of KDC
- 2 Time synchronisation and lifetime of tickets
- 3 Weak passwords (*dictionary attack*)
- 4 Session keys on the client
- 5 One-time authentication only (*single sign on*)

Weaknesses of the Kerberos Protocol

What other vulnerabilities of the Kerberos protocol could an attacker use?

Weak Points for Attacks

- 1 Key management of KDC
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Weak Point 1: Key management of KDC

- KDC is a *single point of failure*
- KDC keys are only protected with a **single master key**
- **DoS attacks** highly effective (*denial of service attack*)

Ticket Lifetime

Weak Point 2: Replay Attacks

- 1 Log the messages of Step ⑤
- 2 Replay these messages at a later time
- 3 Use a service (e.g. print service) as a different person

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Assumptions

- Lifetime of messages from Step ⑤ has not expired at the time of replay, or
- Clock of the print server was manipulated

Ticket Lifetime

Which protocol step is particularly vulnerable to replay attacks on Kerberos? What would be a successful scenario from an attacker's point of view?

Weak Point 2: Replay Attacks

- 1 Log the messages of Step ⑤
- 2 Replay these messages at a later time
- 3 Use a service (e.g. print service) as a different person

Assumptions

- Lifetime of messages from Step ⑤ has not expired at the time of replay, or
 - Clock of the print server was manipulated
- Kerberos is **not secure against replay attacks**, because the attack can only be mitigated by using time stamps!

Why can't timestamps provide absolute protection against replay attacks?

Weak Passwords

Weak Point 3: Dictionary Attack

- 1 Intercept messages of Step ① and ②
- 2 Convert potential passwords into DES/AES keys using the selected hash function (e.g. MD5 or SHA1)
- 3 Decrypt messages of Step ② with AES/DES key and perform a plausibility check, e.g. check for validity of time stamps

Weak Passwords

What other vulnerabilities of the Kerberos protocol could an attacker use?

Weak Point 3: Dictionary Attack

How was it possible to avoid an explicit storing of passwords?

- 1 Intercept messages of Step ① and ②
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- 3 Decrypt messages of Step ② with AES/DES key and perform a plausibility check, e.g. check for validity of time stamps

What are the main differences between Kerberos v4 and v5?

Kerberos v4 has an additional weakness

- no *Pre-Authentication*, i.e. Step ① gives no information on whether the applicant knows a password
- AS sends TGT for Step ② without any check
- The attacker is able to send any requests in the name of the person to be attacked in order to evaluate the answers

Weaknesses of the Kerberos Protocol

Weak Point 4: Session keys on the client

- Assumption: Client is a single-user machine is not realistic
- Attacker accesses session keys on the client and get access to the complete network
- ➔ Authentication via client IP address is useless
- ➔ Kerberos v5 supports additional challenge-response authentication

Weaknesses of the Kerberos Protocol

What other vulnerabilities of the Kerberos protocol could an attacker use?

Weak Point 4: Session keys on the client

- Assumption: Client is a single-user machine is not realistic
 - Attacker accesses session keys on the client and get access to the complete network
- Authentication via client IP address is useless
- Kerberos v5 supports additional challenge-response authentication
- What are the main differences between Kerberos v4 and v5?

Weak Point 5: One-time authentication

- Single sign-on is an advantage for easy handling
- Disadvantage: Attacks have a large impact, protection of sensitive data requires additional security mechanisms

Kerberos Realms

– How works interrealm authentication? –

Kerberos Realms

Realm

- Consists of a KDC and the users assigned to it
- Realm name is often based on DNS names
name[/instance]@REALM (e.g. *helke/admin@TU-COTTBUS.DE*)

What are the main differences between Kerberos v4 and v5?

Cross-Realm Authentication (only Kerberos v5)

- Using services of other realms without entering password
- Assumption: There exists a trust relationship between the user realm and the other realm

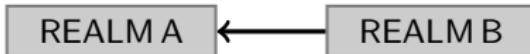
Relations between Realms

- 1 Direct trust relationship
- 2 Transitive trust relationship
- 3 Hierarchical trust relationship

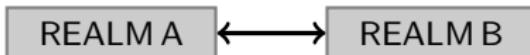
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1. Direct Trust

→ REALM B trusts REALM A



→ REALM A trusts additionally REALM B



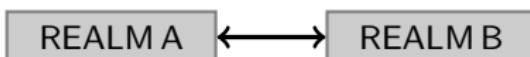
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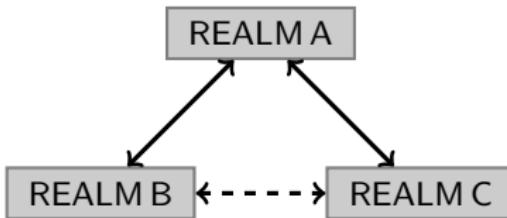
2. Transitive Trust



→ REALM C trusts additionally REALM A

Relations between Realms (2)

3. Hierarchical Trust



- REALM C trusts **additionally** REALM B and vice versa
- **Trust relationship** is derived via transitivity

Cross-Realm Authentication

Procedure

- 1 Request a **TGT** from your own **AS** that will be accepted by **your own TGS**
- 2 Request a **TGT** from **your own TGS** that will be accepted by **an external TGS**
- 3 Request a **Service Ticket** from **the external TGS** that will be accepted by **an external Service**

Summary

Comparison of Kerberos v4 and v5

What are the main differences between Kerberos v4 and v5?

Lifetime of Tickets

- v4: maximum 21 hours
- v5: maximum until 31.12.1999
- In addition, v5 allows to renew tickets and to define the validity of a ticket into the future

Encryption & Hash Functions

- v4: DES & MD5 are fixed
- v5: selectable (e.g. AES & SHA1)

Pre-Authentication

- v4: not supported → useable for active dictionary attacks
- v5: request ① is encrypted and is used for authentication

Summary and Conclusions

- Kerberos protocol is used to authenticate communication partners in a network and to exchange a session key
- Kerberos v4 has many security vulnerabilities and should therefore not be used anymore
- Kerberos v5 is also vulnerable, but with the right configuration it increases the security level considerably
- Kerberos is widely used and can be deployed on various platforms