# Authentication

***Abstract***

*This section introduces general concepts about user authentication. Security aspects of authentication by password are presented. Schemes of authentication by Challenge & Response and One-Time Password are reviewed, including the Lamport's hash chain procedure. Schemes based on security tokens and biometrics are mentioned. The Kerberos system for key distribution and indirect authentication is presented.*

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## Outline

- **General concepts of authentication**
- Username and password
- Challenge and response
- One-Time Password
- Biometrics
- Kerberos



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## Authentication and Authorization

- *Authentication*: guaranteeing the identity of someone or something
  - of a user
  - of a machine
  - of the source of data
  - IETF RFC 4949 definition: the process of verifying an identity claimed by or for a system entity
  - NIST definition: the process of establishing confidence in user identities that are presented electronically to an information system
- *Authorization*: determining what resources or services an authentic entity can access
  - authentication does not imply authorization
    - Alice is authorized to access a service, but Bob is not
  - authorization depends on authentication
    - only the true Alice is authorized



## Steps of Authentication

- Registration
  - the initial requirement of user authentication is that the user has been registered with the system
- Identification
  - the *claimant* presents an identifier to the *verifier*, i.e. the authenticating system
- Verification
  - authentication information is presented or generated, which proves the binding between the entity and the identifier

## Types of Authentication

- Local authentication
  - the user accesses a local system (e.g., laptop)
- Direct (remote) authentication
  - the user accesses directly a remote system, which provides the service (e.g., FTP server)
- Indirect authentication
  - authentication is delegated to a third party (e.g., Kerberos)
- Off-line authentication
  - services decides about authentication autonomously, without contacting the user or authentication server (e.g., PKI certificates)



## Means of Authentication

- *What you know*
  - password, PIN, …
- *What you have*
  - cryptographic keys, keycard, smart card, USB dongle, … (a.k.a.: token)
- *What you are*
  - static biometrics: fingerprint, retina, face
- *What you do*
  - dynamic biometrics: voice pattern, handwriting

- Combined authentication
  - two factors: USB dongle + fingerprint
  - three factors: smartcard + its PIN + fingerprint

## Security of Authentication

- Security of credentials *transmission*
  - on authentication, credentials should be not transmitted as plain text, or not even transmitted
  - otherwise, Oscar can eavesdrop credentials and pretend to be Alice with Bob
- Security of credentials *storage*
  - credentials must not be stored as plaintext in a data base
  - otherwise, if the system is compromised, an attacker can impersonate anyone whose credentials have been stolen



## Outline

- General concepts of authentication
- **Username and password**
- Challenge and response
- One-Time Password
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### What You Know
## Username and Password

- The first and simplest authentication method
  - the username is public
  - security is based on *secrecy of password* (Kerckhoffs' Principle)
- Username and password should be not transmitted as plain text…
  - …but often are (with direct or indirect authentication via TCP)
  - eavesdropping is a problem
- Username and password must not be stored as plaintext in the DB
  - a digest (*hash*) of passwords is stored
  - storing just the hash of password is not enough
    - password guessing by dictionary attack
    - open source tools can be very efficient (Hashcat on GPU)



## Password Strength: Entropy

- *Entropy:* a measure of *unpredictability* of the state, or equivalently of the *information content* of a message, or of the *average information content* of a source (by Claude E. Shannon, A Mathematical Theory of Communication)
- Let $X$ be a memoryless source of messages $x$ over a finite alphabet
  $$x \in \{x_1, x_2, \ldots, x_N,\}$$
  with probability distribution
  $$p(x_i) = P(x=x_i\}$$
- The *Information* [bit] in a single message $x = x_i$ is defined as
  $$I(x) = -\log_2 ( p(x_i) ) \geq 0$$
- The *source Entropy* is its *average Information* (per character) over the alphabet
  $$H(X) = -\sum_{i=1..N} p(x_i) \cdot \log_2 ( p(x_i) ) \geq 0$$

## Entropy of a Password

- Example of simple alphabetical password $X$
  - a combination of 7-bit ASCII characters
  - excluding 32 control characters
  - 95 printable characters, supposed with same probability
- $H(X) = \log_2 95 \approx 6.57$ bit/character
- A 10-character random password has 65.7 bit of entropy (information)
- Using a real language word (writable with Latin alphabet)
  - 27 letters and space $\Rightarrow H(X) = \log_2 27 \approx 4.75$ bit/character
  - but characters have not same probability…
  - considering a sample Italian language frequency distribution of letters ("I Promessi Sposi", Alessandro Manzoni) $\Rightarrow H_1(X) = \approx 3.97$ bit/character
- But real language text is not memoryless...
  - characters in words and phrases are correlated



## Entropy of a Passphrase

- Considering the correlation in a sequence of characters of a real language phrase, the entropy of a phrase is much lower
- Based on distributions of groups of *n* letters (digrams, trigrams, …) in a large sample text ("I Promessi Sposi", A. Manzoni) and on the definition of *conditional entropy*, the average entropy can be evaluated
  - $H_1(X) = \approx 3.97$ bit/character $H_2(X) = \approx 3.15$ bit/character
  - $H_3(X) = \approx 2.67$ bit/character $H_4(X) = \approx 2.22$ bit/character
  - $H_5(X) = \approx 1.87$ bit/character ….
- Shannon estimated the entropy of an English language text as in range $0.6 < H < 1.3$ bit/character
  - today the entropy of a password or passphrase is estimated on the order of about 2 bit/character

## Security of a Password

- Various ways envisaged to identify a password
  - traffic sniffing
    - when transmitted as plain text in direct or indirect authentication
  - online guessing
    - the attacker interacts directly with the service making attempts (POP3, FTP,…)
    - countermeasures: locking accounts, slowing down next attempts
  - offline guessing
    - brute force and dictionary attacks to the hashed password file
    - countermeasures: salting, encrypt the pw file, make it accessible only by admin
  - more creative approaches
    - social engineering
    - shoulder surfing
    - phishing
    - keylogger
    - Van Eck sniffing (pick up monitor radiations)
    - mouse pad survey
    - keyboard acoustic emanation



## Example: Password in UNIX

- UNIX systems store account and password information in two files
  - */etc/passwd*: account generic information, readable by everyone
  - */etc/shadow* (Linux) or */etc/master.passwd* (BSD): password hashes, readable only by root
- The password digest is made by a *slow* hash function with *salt*
  - crypt: 25 modified DES encryptions
  - crypt-MD5: modified crypt based on MD5 (1000 iterations)
  - crypt-blowfish
  - crypt-SHA1

## Cracking Weak Passwords

- Multi-purpose tools are available to crack weak passwords by various means, including
  - offline cracking of hashed password files (Windows, Unix, etc.)
  - brute force and dictionary attacks to the hashed password file
  - traffic sniffing
  - WLAN key recovery
  - GPU to take advantage of parallel computing
- Some of the most popular multi-purpose tools
  - John the Ripper
  - Cain & Abel (for Microsoft)
  - Hashcat



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- General concepts of authentication
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- **Challenge and response**
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## What You Know
## Challenge and Response

- It solves the problem of eavesdropping, as *the credentials are not transmitted*
  - the client must be able to *use a secret information, proving he knows it*
- Challenge
  - the server S sends a pseudo-random sequence
- Response by the client C may be
  - by way of *symmetric key encryption*:
    C encrypts the challenge using a shared secret symmetric key $K$
    - $E_K\{challenge\}$
  - by way of a *hash function*: C concatenates the challenge with a shared secret symmetric key $K$ and then hashes it
    - $h(\, challenge \,||\, K\,)$
  - by way of *public key encryption*:
    C encrypts the challenge with its private key $K_{Cp}$
    - $E_{KCp}\{challenge\}$



## Vulnerability of Challenge-and-Response Authentication

- Challenge-and-Response authentication is secure on transmission, but vulnerable on storage of credentials (in case of symmetric encryption)
  - the server must know the secret
  - brute force and dictionary attacks to the file of hashed secrets
  - public-key encryption solves this vulnerability

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### What You Know
## One-Time Password (OTP)

- Another way to avoid the problem of eavesdropping credentials
- One-Time Password (OTP): a password that is valid only for one login session or transaction
  - not vulnerable to replay attacks
- The user is given an ordered list of passwords, to be used one after the other, each for a single time
- OTPs are transmitted from the user to the server as plain text
- OTPs can be generated in advance and transmitted as bulk to the user, or generated by a specific algorithm on software or hardware device
  - token + PIN: *what you have* + *what you know*

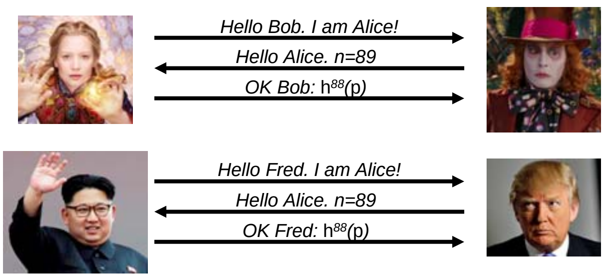
### One-Time Password
## Lamport's Hash Chain Scheme

- A Challenge-And-Response scheme to generate OTPs (L. Lamport, 1981), guaranteeing security of both transmission and storage
- Based on repeated computation of a secure *one-way* hash function
- The user Alice knows a password $p$
- The server Bob, for each user, knows
  - the user's name and an integer seed $n$ (e.g., $n$=1000)
  - the result of $h^n(p) = h(h(h(\ldots h(p) \ldots)))$ (computed $n$ times)
- Authentication process of Alice with Bob:
  - Alice sends her user's name (plain text)
  - Bob replies the integer $n$ (plain text)
  - Alice sends $h^{n-1}(p)$
  - Bob computes $h(h^{n-1}(p))$ and compares it to the stored value $h^n(p)$
  - Bob deletes $h^n(p)$ and replaces it with the new value $h^{n-1}(p)$
  - next time, Bob will send the integer $n$-1



### Security Threats of the Lamport's Scheme
## Two Authentication Servers?

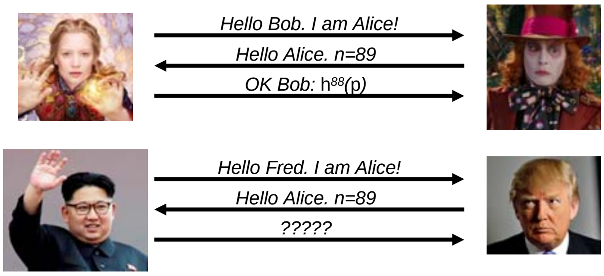
- Alice wants to be authenticated by two servers Bob and Fred
  - Fred sends $n$+1 and Bob sends $n$
  - Alice sends $h^n(p)$ to Fred and $h^{n-1}(p)$ to Bob
- Oscar may intercept $h^{n-1}(p)$ and, after Fred has sent $n$+1 and Alice has replied $h^n(p)$, use it to get authentication from Fred as Alice



### Security Threats of the Lamport's Scheme

## Two Authentication Servers? Countermeasure

- A different public *salt* (seed) $s$ is assigned to each server, stored on both server and user
  - the server stores $h^n(p||s)$
  - Alice sends $h^{n-1}(p||s)$






### Security Threats of the Lamport's Scheme

## Small-*n* Attack

- After $n$ authentications, the system has to be re-inizialized
- Small-$n$ attack: Oscar impersonates Bob
  - Oscar waits for Alice to request authentication
  - Oscar sends Alice a small n (e.g., 50)
  - Alice sends $h^{49}(p)$
- If the real Bob is storing a large $n$>50, Oscar can now get authentication as Alice $n$-50 times

What You Have
## Security Token

- Hardware device to generate OTPs
  - *time-based OTP token (synchronous token)*: the OTP is computed based on the current time and is valid in the current time window (need of time synchronization between tokens and server)
  - *counter token:* the OTP is computed based on a counter, incremented each time (need to keep tokens aligned on the server)




## Two-Factor Security Token

- Only the legitimate owner can use the token
  - *what you have* (token device) + *what you know* (PIN)
- Different alternative approaches to incorporate a PIN in the OTP
  - Alice gives both the PIN and the OTP
    - the server verifies both the PIN and the OTP
  - the PIN is incorporated in the OTP computation
    - the OTP is not valid, if the correct PIN has not been given to the token
  - the token device requires a PIN to run the algorithm and generate an OTP

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### What You Are / What You Do
## Biometric Patterns

- A way to obviate the weakness of users
  - passwords can be disclosed or guessed easily, tokens can be lost
- Various possible applications
  - *authentication* of a user (search one-to-one)
    - is the user really who declares to be?
  - *identification* of a user (search one-to-many)
    - given a sample, can we associate it to a single person or to a small group?
    - the database is assumed *complete*
  - *uniqueness* (is the user present in the current database?)
    - given a sample, can we determine whether the owner is already registered?
    - the database is not assumed *complete*
- *What you are* or *what you do*?
  - static biometrics: physical characteristics
  - dynamic biometrics: behavior patterns
- Search in the database by *closest match*

## What You Are
# Static Biometrics: Physical Characteristics

- Fingerprint
  - unique pattern, different also for homozygous twins
  - advances: 3D acquisition, electrical measurement, thermal fingerprint
- Hand geometry
  - 3D acquisition and measurement of shape, finger length,…
- Retina or iris
  - image acquisition with a specific camera
  - unique pattern, different also for homozygous twins
- Face
  - image acquisition and geometric pattern identification
  - homozygous twins are not discriminated
- Others
  - thermogram, ear image, odor analysis, DNA,…

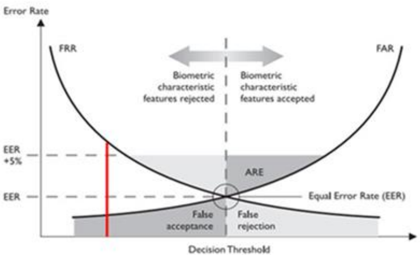


## What You Do
# Dynamic Biometrics: Behavior Patterns

- Speech recognition
  - identification of a vocal "fingerprint"
  - can be deceived using high-quality recordings
- Signature dynamics (on a tablet)
  - analysis of the image and of the variations of pen pressure and speed
- Typing speed pattern
  - analysis of the time series of keyboard hits

## Accuracy of Biometric Authentication

- *False Acceptance Rate* (FAR)
  - the measure of the likelihood that the system will incorrectly accept an access attempt by an unauthorized user
  - the ratio of the number of false acceptances divided by the number of identification attempts
- *False Rejection Rate* (FFR)
  - the measure of the likelihood that the system will incorrectly reject an access attempt by an authorized user
  - the ratio of the number of false rejections divided by the number of identification attempts






## Performance of Biometric Authentication

- FAR and FFR performance achieved by current biometric systems is still not adequate to allow its adoption as single authentication factor
- Weak points of *single-factor biometric systems*
  - noise and impairments in acquired data (e.g., dirty sensor or finger)
  - intra-class variation (e.g., variable positioning vs. the camera)
  - inter-class similitude (e.g., persons with very similar faces)
  - non-universality (not all individuals present adequate quality of the unique features, e.g. damaged fingers)
  - spoofing (e.g., fingerprint mould)
- *Multiple-factor biometric systems* are under study

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## Kerberos

- Developed at MIT (Athena Project, 1989)
- Provides a centralized service for *key distribution* and *indirect authentication* in an open, untrusted and distributed environment
  - users at workstations access services on servers throughout the network
  - servers restrict access to authorized users and authenticate requests for specific services
    - malicious users can gain access on legitimate workstations, spoof IP address
    - attackers can read, modify, add packets in the protocol traffic
  - based on the Needham-Schroeder protocol with trusted third-party *Authentication Server*
  - based exclusively on *symmetric cryptography* (no public key)
  - requires clock *time synchronization* (e.g., by NTP)
- Two versions are in use
  - Kerberos v4 (Athena Project, 1989)
  - Kerberos v5 (Internet Standard RFC 4120)

## Kerberos v4
# A Simple Authentication Dialogue

- Open untrusted environment
  - anyone can apply to any server for any service
  - to counteract *impersonation*, an Authentication Server (AS) stores passwords of all users in a central database and knows a symmetric key with each server
- The user C requests access to server S

**C→AS:** $ID_C \,||\, P_C \,||\, ID_S$ *(plain text!)*

**AS→C:** *Ticket* *(AS has checked identity of C and if C is allowed on S)*

**C→S:** $ID_C \,||\,$ *Ticket*

*Ticket* $= \{ ID_C \,||\, AD_C \,||\, ID_S \}_{K_{S\text{-}AS}}$

*$ID_C$, $P_C$, $ID_S$: identifier and password of user on client C or of server S*
*$AD_C$: network address of user on client C*
*$K_{S\text{-}AS}$: symmetric key shared by S and AS*



## Kerberos v4
# Improving the Simple Authentication Dialogue

- Unsolved problems in this simple authentication dialogue
  - password is supplied as plain text
  - each time a user requests a ticket must supply the password
    - tickets should be reusable throughout logon sessions
    - however a user needs a ticket for every different service
- The simple scheme has to be improved
  - password not transmitted as plain text
  - a Ticket-Granting Server (TGS) is introduced to distribute tickets to access each service
  - tickets can be used repeatedly
  - two types of tickets
    - Ticket Granting Ticket (TGT), which allows requesting a regular Ticket
    - regular Service Ticket (ST), which allows to access a certain service

## Kerberos v4
# A More Secure Authentication Dialogue

- Once per user logon session
  - **C→AS:** $ID_C \| ID_{TGS}$
  - **AS→C:** $\{Ticket_{TGS}\}_{K_{C\text{-}AS}}$
- Once per type of service
  - **C→TGS:** $ID_C \| ID_S \| Ticket_{TGS}$
  - **TGS→C:** $Ticket_S$
- Once per service session
  - **C→S:** $ID_C \| Ticket_S$

$Ticket_{TGS} = \{ ID_C \| AD_C \| ID_{TGS} \| TS_1 \| Lifetime_1 \}_{K_{TGS\text{-}AS}}$
$Ticket_S = \{ ID_C \| AD_C \| ID_S \| TS_2 \| Lifetime_2 \}_{K_{S\text{-}TGS}}$

*$ID_{TGS}$, identifier of the Ticket-Granting Server*
*$K_{C\text{-}AS}$: symmetric key of C and AS, derived from the password of C*
*$K_{TGS\text{-}AS}$: symmetric key of TGS and AS*
*$K_{S\text{-}AS}$: symmetric key of S and AS* *TS: time stamp*



## Kerberos v4
# Yet Improving the Authentication Dialogue

- If Lifetimes are short ➔ the user must supply password often
- If Lifetimes are long ➔ replay attacks
  - *$Ticket_{TGS}$* can be eavesdropped and replayed to request *$Ticket_S$* impersonating the legitimate user
  - *$Ticket_S$* can be eavesdropped and replayed to request service impersonating the legitimate user
  - simple IP spoofing is enough to impersonate the user
- Mutual authentication is needed
  - to authenticate users to the server ➔ no replay attack by false user
  - to authenticate the server to users ➔ no false server

## Summary of Kerberos v4 Dialogue

- Authentication Service Exchange to get the Ticket-Granting Ticket
  - **1) C→AS:** $ID_C \,||\, ID_{TGS} \,||\, TS_1$
  - **2) AS→C:** $\{ K_{C\text{-}TGS} \,||\, ID_{TGS} \,||\, TS_2 \,||\, Lifetime_2 \,||\, Ticket_{TGS} \}_{K_{C\text{-}AS}}$
- TG Service Exchange to get the Service Ticket
  - **3) C→TGS:** $ID_S \,||\, Ticket_{TGS} \,||\, Authenticator_{C1}$
  - **4) TGS→C:** $\{ K_{C\text{-}S} \,||\, ID_S \,||\, TS_4 \,||\, Ticket_S \}_{K_{C\text{-}TGS}}$
- Client/Server Authentication Exchange to get service
  - **5) C→S:** $Ticket_S \,||\, Authenticator_{C2}$
  - **6) S→C:** $\{ TS_5+1 \}_{K_{C\text{-}S}}$

$Ticket_{TGS} = \{ K_{C\text{-}TGS} \,||\, ID_C \,||\, AD_C \,||\, ID_{TGS} \,||\, TS_2 \,||\, Lifetime_2 \}_{K_{TGS\text{-}AS}}$

$Ticket_S = \{ K_{C\text{-}S} \,||\, ID_C \,||\, AD_C \,||\, ID_S \,||\, TS_4 \,||\, Lifetime_4 \}_{K_{S\text{-}TGS}}$

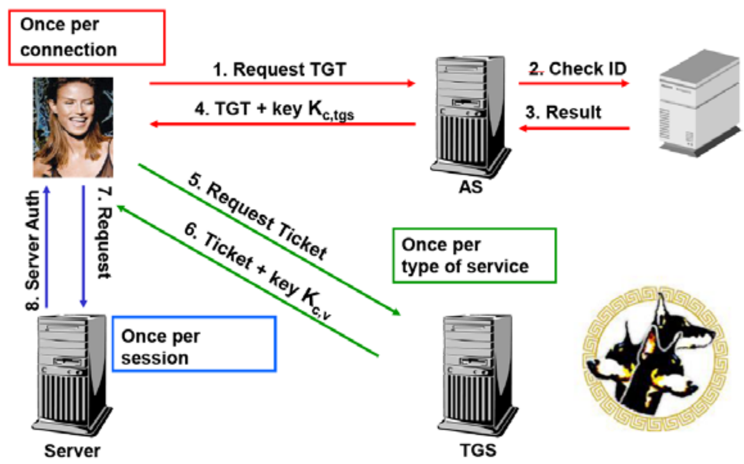
$Authenticator_{C1} = \{ ID_C \,||\, AD_C \,||\, TS_3 \}_{K_{C\text{-}TGS}}$

$Authenticator_{C2} = \{ ID_C \,||\, AD_C \,||\, TS_5 \}_{K_{C\text{-}S}}$

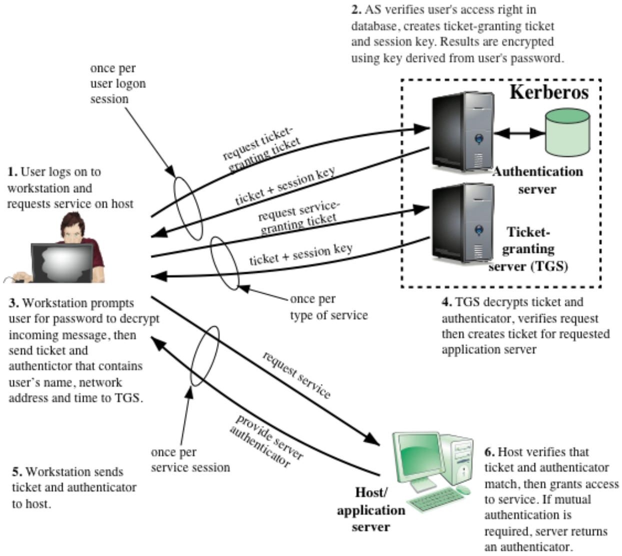




## Overview of Kerberos v4 Dialogue



## Kerberos v4
# Overview of Kerberos v4 Dialogue






## Kerberos v4
# Kerberos Multiple Realms

- A *Kerberos Realm* consists of one Kerberos server, a few clients, a few application servers
  - i.e., a set of managed nodes that share the same Kerberos database, which resides on the Kerberos master computer (physically secured)
- The Kerberos server
  - knows the user ID and hashed passwords of all (registered) users
  - shares a secret key with each (registered) application server
- Networks under different administrations (different policies) typically belong to distinct realms
- Users in one realm may need access to servers in other realms
  - procedure for inter-realm authentication

From Kerberos v4 to Kerberos v5

## Limitations and Improvements (1)

- Dependence on encryption system
  - v4 requires DES encryption ➔ v5 may use any encryption system
- Dependence on IP
  - v4 requires IP addresses ➔ v5 may use any network addressing system
- Byte ordering of messages
  - v4 uses a variable byte ordering scheme ➔ v5 uses a single standard (Abstract Syntax Notation 1 and Basic Encoding Rules)
- Ticket lifetime
  - v4 encodes lifetime as 8 bit in 5' units (max 256×5' = 21h) ➔ v5 specifies explicit start and end times
- Authentication forwarding
  - v5 allows a client to access a server, and this server to access another server on behalf of the client (e.g., a print server accesses a file server)
- Inter-Real authentication improved



From Kerberos v4 to Kerberos v5

## Limitations and Improvements (2)

- Double encryption in messages 2 and 4 is avoided
- Non-standard PCBC DES mode is replaced by standard CBC DES
  - Propagating Cipher Block Chaining was adopted to include integrity check besides encryption, but it was proved to be vulnerable
- Sub-session keys are introduced in v5 to avoid repeated use of the same session key for many connections
- Both v4 and v5 are somehow vulnerable to offline password attacks (brute force or dictionary attacks)