Kerberos

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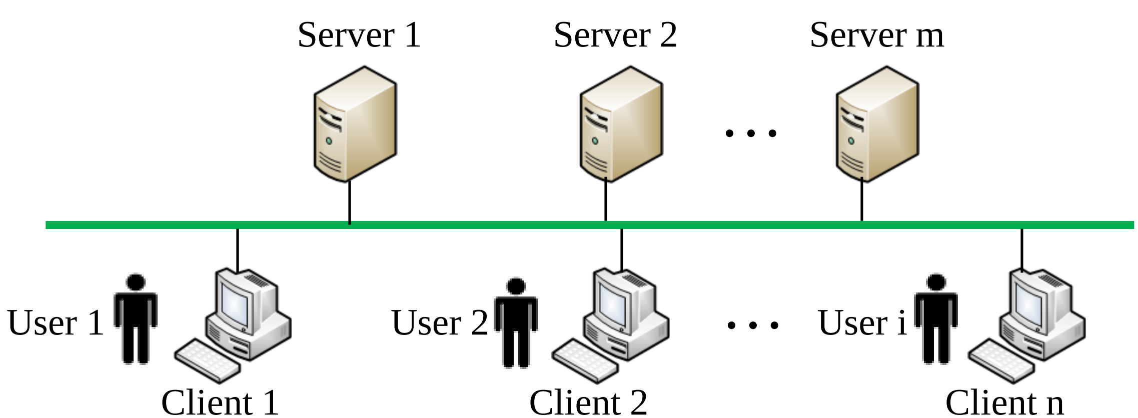
The Problem

- Problem:

  Multiple users
  Multiple client computers
  Multiple server computers

  we need
  1. Authentication
  2. Authorization
  3. Confidentiality
  4. Freshness
  5. Auditing

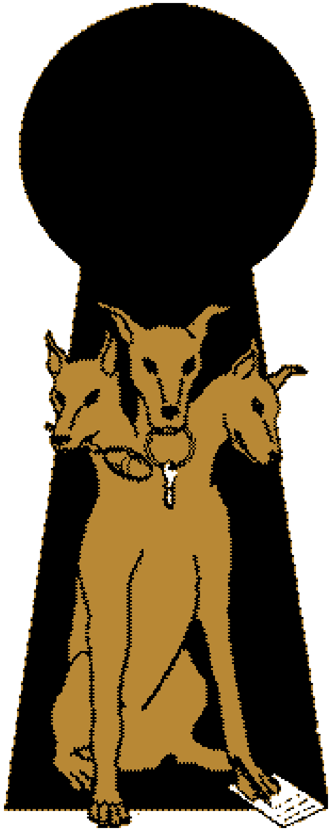


"On the Internet, no one knows you're a dog."

- How should we do authentication here?
  – Users need to prove their identities when requesting services at servers from client machines.

Kerberos

- Kerberos is an **authentication** and **authorization** protocol
- Kerberos uses a **trusted third party** authentication service that enables clients and servers to establish authenticated and secure communication.
- Kerberos provides **single sign-on** capability using a centralized repository of accounts.
- Relies entirely on **symmetric cryptography**
- Kerberos provides an **audit trail of usage**.
  - How? You should be able to answer after this lecture.
- Developed at MIT: two versions, Version 4 and Version 5 (specified as RFC1510)
- http://web.mit.edu/kerberos/www
- Used in many systems, e.g., Windows 2000 and later as default authentication protocol
- In Greek mythology, Kerberos means a many headed dog, commonly three, perhaps with a serpent's tail, the guardian of the entrance of Hades."
  - the modern Kerberos was intended to have three components to guard a network's gate: **authentication**, **accounting**, and **audit.**



Requirements

- Security
  - A network eavesdropper should not be able to obtain the necessary information to impersonate a user.
- Transparency
  - Users shouldn’t notice authentication taking place beyond the requirement to enter a password.
- Scalability
  - The system should be capable of supporting large numbers of clients and servers.
- Reliability
  - For all services that rely on Kerberos for access control, lack of availability of the Kerberos service means lack of availability of the supported services.

Threat Model

- User impersonation
  - A user may gain access to a particular workstation and pretend to be another user operating from that workstation.
- Network address impersonation
  - A user may alter the network address of a workstation so that the requests sent from the altered workstation appear to come from the impersonated workstation.
- Eavesdropping, tampering and replay
  - A user may eavesdrop on exchanges and use a replay attack to gain entrance to a server or to disrupt operations.

Straightforward Solution 1

- Solution 1: Each client handles authentication & authorization by itself using its database.

- Drawbacks:
  - All user databases need to be synchronized across all client PCs. Management tasks like adding or deleting a user need to be performed on every client PC. Obviously this solution is not scalable with the number of client PCs.

Straightforward Solution 2

- Solution 2: Each server handles authentication & authorization by itself using its database.

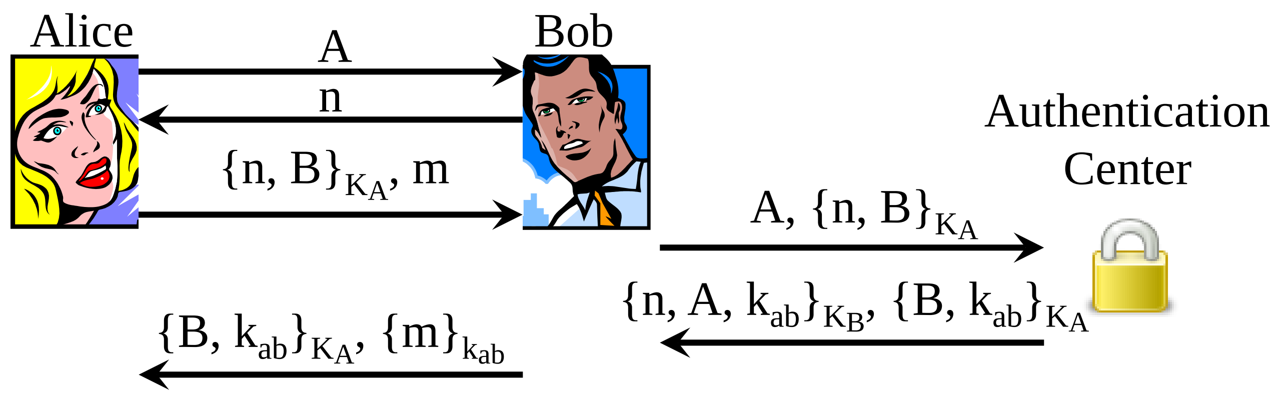
- Drawbacks:
  - All user databases need to be synchronized across all servers. Management tasks like adding or deleting a user need to be performed on every server. This solution is not scalable with the number of servers. It is hard to manage user accounts and access rights.

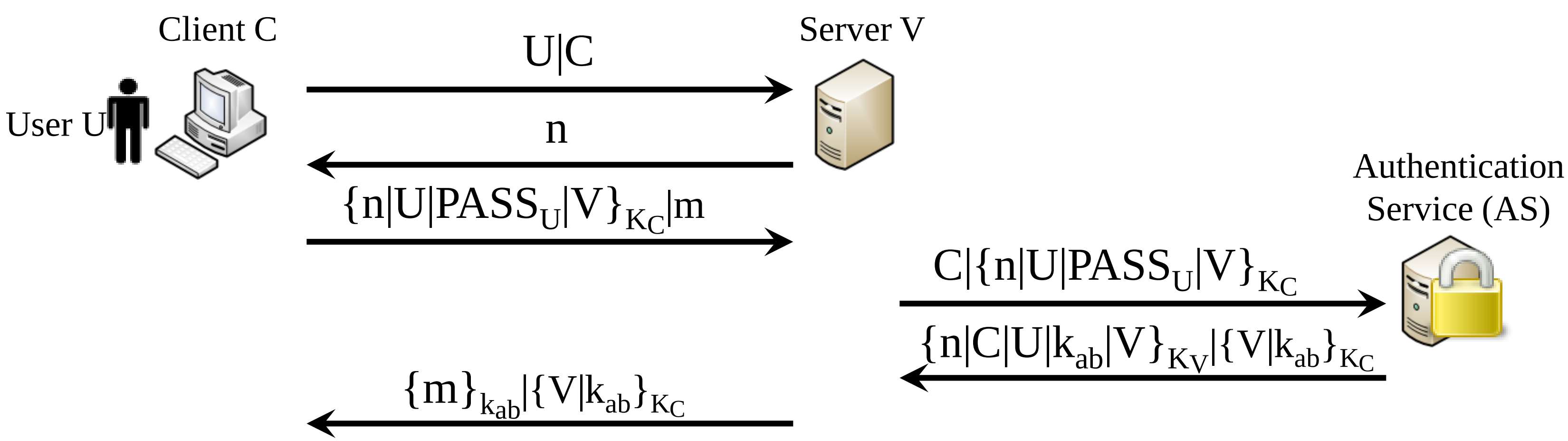
Kerberos

- Key management:
  - Every server does have a shared key with AS
  - Every user has a password with AS
  - Every client does NOT have a shared key with AS
    - Clients mean the client PCs. Users mean human users.
    - Why?
      - We want the clients to be “dummies”. This not only makes the management of clients easier but also makes the system secure against client compromises.

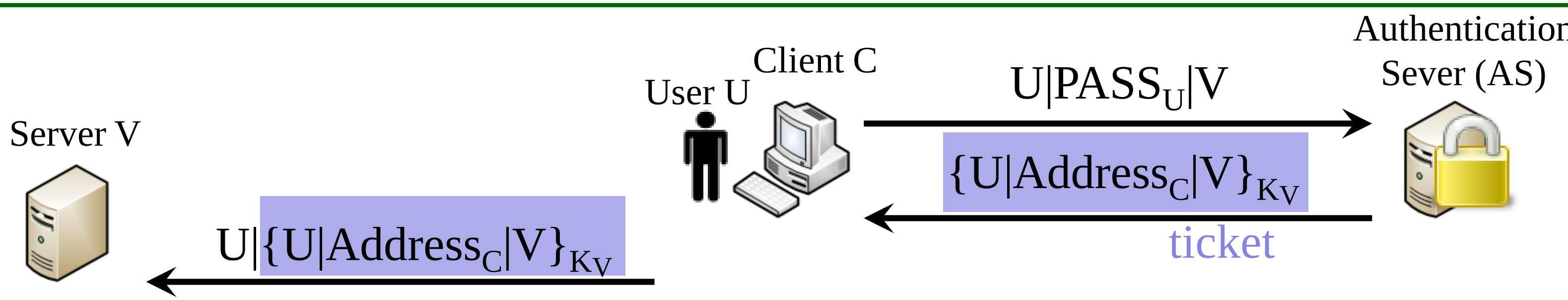
Kerberos: Alex Version 1

- If every client has a shared key with AS, then we can use the symmetric key based authentication protocol using trusted third party.
  - Note: Kerberos versions 1-3 were not published. This is “Alex” version of Kerveros Version 1 for teaching purposes.





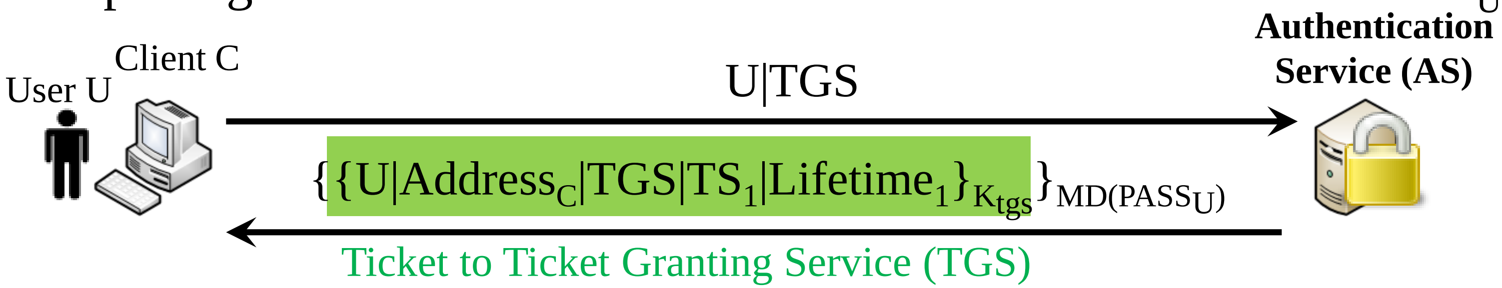
Kerberos: Alex Version 2



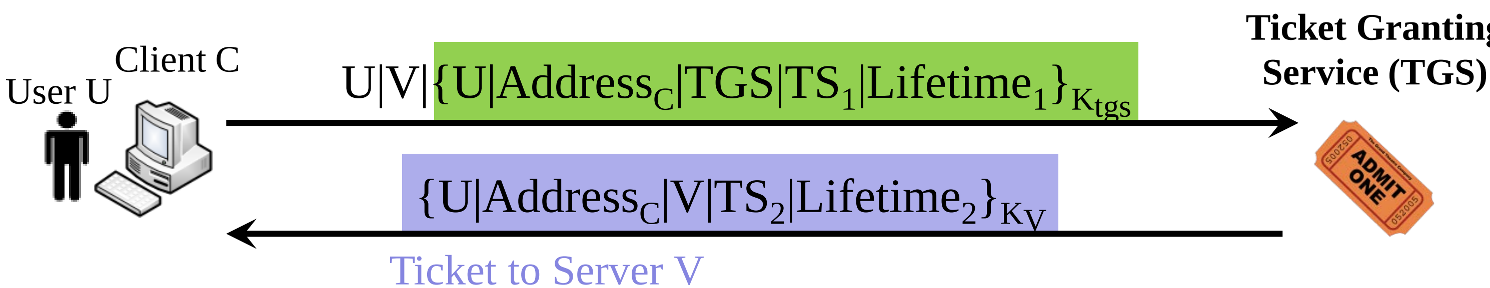
- Why does the ticket include Address_C?
  - Otherwise another malicious client can steal a ticket and replay it.
  - Yes, an attacker can still replay it by changing the address of a compromised client, but he has to wait client C to power off.
- Why encrypted with K_V?
  - Prevent ticket from being forgeable.
- Defect of this protocol:
  - Password of U is sent in plaintext.
  - How to encrypt user U's password?
    - Since both Client C and AS knows U's password, they can generate a key from $MD(PASS_U)$.

Kerberos: Alex Version 3 (1/2)

- Step 1: Authentication
  - Once per logon session. AS needs to search in user database for $PASS_U$



- Step 2: Authorization
  - Once per type of service.
    - TGS needs to search in authorization database or access control rules.



  - Once per service session

Kerberos: Version 3 (2/2)

- Why not combine these two steps?
  - If we do, then for each server that U wants to access, AS needs to search in its user database and authorization database.
- Why use timestamp?
  - Otherwise, an attacker can steal the ticket, wait for C to power off, and reconfigure his client using C's address, and then replay the ticket.

Defects of Version 3

- Major Defect 1: Only one-way authentication. Client C cannot authenticate AS, TGS, or V.
  - How to achieve mutual authentication? Think: What can be used as a shared secret? To achieve mutual authentication, there must be some secret shared.
    - U’s password is the shared secret between C and AS.
  - Then what about C and TGS? What can be used as a shared secret?
    - We can let AS to create one for C and TGS.
  - Then what about C and V? What can be used as a shared secret?
    - We can let TGS to create one for C and V.

Defects of Version 3

- Major Defect 2: TGS cannot know whether $\{U|Address_C|TGS|TS_1|Lifetime_1\}_{K_{tgs}}$ is a replayed one.
  - If lifetime is too short: ASK AS or TGS too often.
  - Similarly, if lifetime is too long, V cannot know whether $\{U|Address_C|V|TS_2|Lifetime_2\}_{K_V}$ is a replayed one.
  - Difficult to choose the right lifetime
- How to solve this problem:
  - In addition to showing me your ticket, prove to me your identity each time you talk to me.
    - C generates an authenticator each time it talks to TGS or V.

Kerberos: Version 4

- Authentication

AS needs to make sure C is not much out of synchronization

User U | Client C | Authentication Service (AS)

$U | TGS | \boxed{TS_1}$ →

← $\{K_{C,tgs} | \boxed{TGS | TS_2 | Lifetime_2} | \{K_{C,tgs} | U | Address_C | TGS | TS_2 | Lifetime_2\}_{K_{tgs}}\}_{MD(PASS_U)}$

for C to authenticate AS

$Ticket_{tgs}$

- Authorization

Authenticator

User U | Client C | Ticket Granting Service (TGS)

$V | \{K_{C,tgs} | U | Address_C | TGS | TS_2 | Lifetime_2\}_{K_{tgs}} | \boxed{\{U | Address_C | TS_3\}_{K_{C,tgs}}}$ →

← $\{K_{C,V} | \boxed{V | TS_4 | Lifetime_4} | \{K_{C,V} | U | Address_C | V | TS_4 | Lifetime_4\}_{K_V}\}_{K_{C,tgs}}$

for C to authenticate TGS

Ticket V

I believe that this is a typo in the original paper

- Authentication & Authorization

User U | Client C | Server V

$\{K_{C,V} | U | Address_C | V | TS_4 | Lifetime_4\}_{K_V} | \{U | Address_C | TS_5\}_{K_{C,V}}$ →

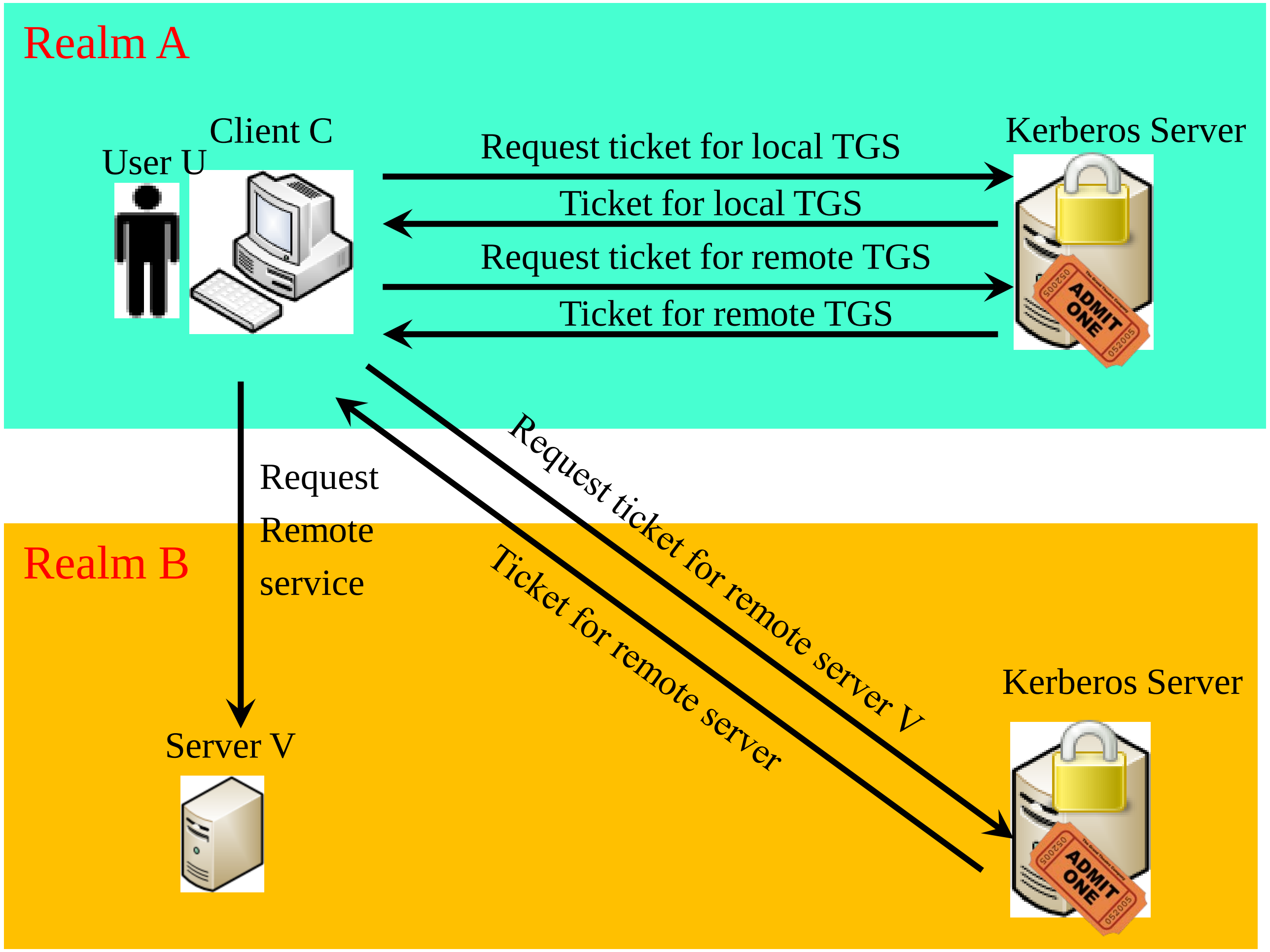
← $\{TS_5+1\}_{K_{C,V}}$

Messages afterwards may or may not be encrypted by the session key $K_{C,V}$, depending on the application.

Kerberos: Version 4

- Why do we need authenticator?
  - To prevent message replay. Although replaying the TGS ticket does not allow attackers to get a fresh server ticket because attackers does not know $K_{C,\ tgs}$, it may cause wrong audit record of user U uses service V.
  - Authenticator is generated very recently.
  - Even if an attacker steals a ticket, because he does not know the shared key between C and TGS and the shared key between C and V, he cannot generate a fresh authenticator.
- Loose synchronization:
  - If TGS current time – TS3 > maximum clock difference between TGS and C, then the authentication fails.
  - If V's current time – TS5 > maximum clock difference between V and C, then the authorization fails.
- The textbook and the original Kerberos paper did not include Lifetime4 in the message from TGS to C outside the server ticket in the protocol specification. But I think it should be included because otherwise C does not know when the server ticket will expire. I believe that this is a typo in the original paper because in the paper the authors said that the format of message from TGS to C is identical to the format of the message from AS to C.

Kerberos: Version 4 – Interrealm Services



- A Kerberos realm is a set of managed nodes that share the same Kerberos database.

Problems of Version 4

- Nonscalable for interrealm authentication
  - n realms need n^2 Kerberos-to-Kerberos relationships
  - Solution: use a hierarchy of realms (i.e., make a tree).

- Double encryption: tickets are encrypted twice.
  - Solution: move the ticket out of the encryption.

- Session key
  - Used by both authenticator and subsequent message encryption cross multiple sessions between C and V. Thus, an attacker may replay a message encrypted by $K_{C, V}$ in a previous session as a message encrypted by $K_{C, V}$ in a later session.
  - Solution: using randomly started sequence numbers.

Problems of Version 4

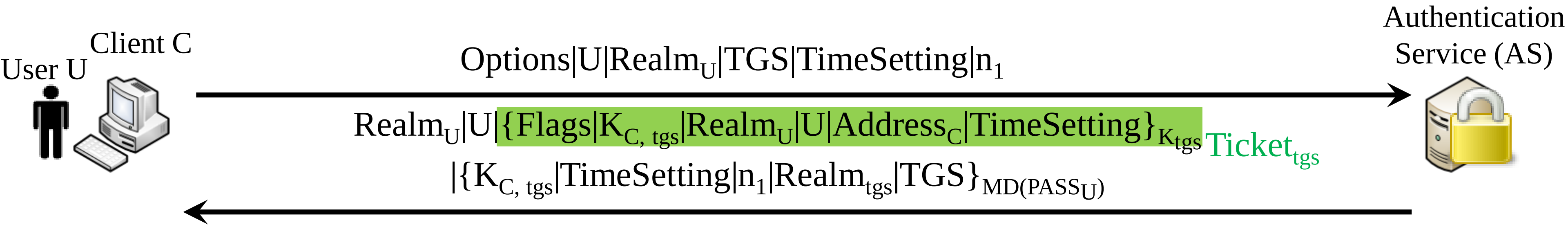
- Engineering problems
  - Encryption depends on DES → Encryption keys are tagged with a type and a length
  - Rely on IP address → Network addresses are tagged with a type and a length
  - Ticket lifetime is 8-bit length. Unit is 5 min and maximum is 21 hours.

    → Ticket includes a start time and ended time
  - Message byte ordering: indicates least significant bytes in lowest/highest address by a tag. It is not convenient.

    → All messages are defined using Abstract Syntax Notation One (ASN.1) and Basic Encoding Rules (BER)
  - PCBC encryption: version 4 uses a non standard mode of DES, .i.e., Propagating Cipher Block Chaining (PCBC). This mode is insecure.

Kerberos: Version 5 (1/2)

- Authentication

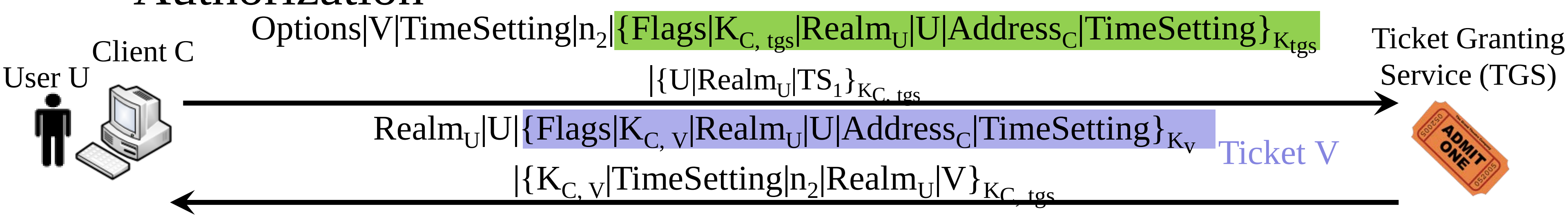


$\text{Options}|U|\text{Realm}_U|\text{TGS}|\text{TimeSetting}|n_1$

$\text{Realm}_U|U|\{\text{Flags}|K_{C,\ tgs}|\text{Realm}_U|U|\text{Address}_C|\text{TimeSetting}\}_{K_{tgs}}$

$|\{K_{C,\ tgs}|\text{TimeSetting}|n_1|\text{Realm}_{tgs}|\text{TGS}\}_{MD(PASS_U)}$

- Authorization



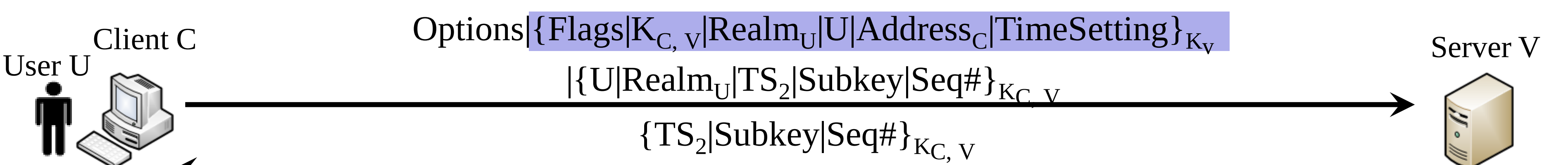
$\text{Options}|V|\text{TimeSetting}|n_2|\{\text{Flags}|K_{C,\ tgs}|\text{Realm}_U|U|\text{Address}_C|\text{TimeSetting}\}_{K_{tgs}}$

$|\{U|\text{Realm}_U|TS_1\}_{K_{C,\ tgs}}$

$\text{Realm}_U|U|\{\text{Flags}|K_{C,\ V}|\text{Realm}_U|U|\text{Address}_C|\text{TimeSetting}\}_{K_V}$

$|\{K_{C,\ V}|\text{TimeSetting}|n_2|\text{Realm}_U|V\}_{K_{C,\ tgs}}$

- Authentication & Authorization

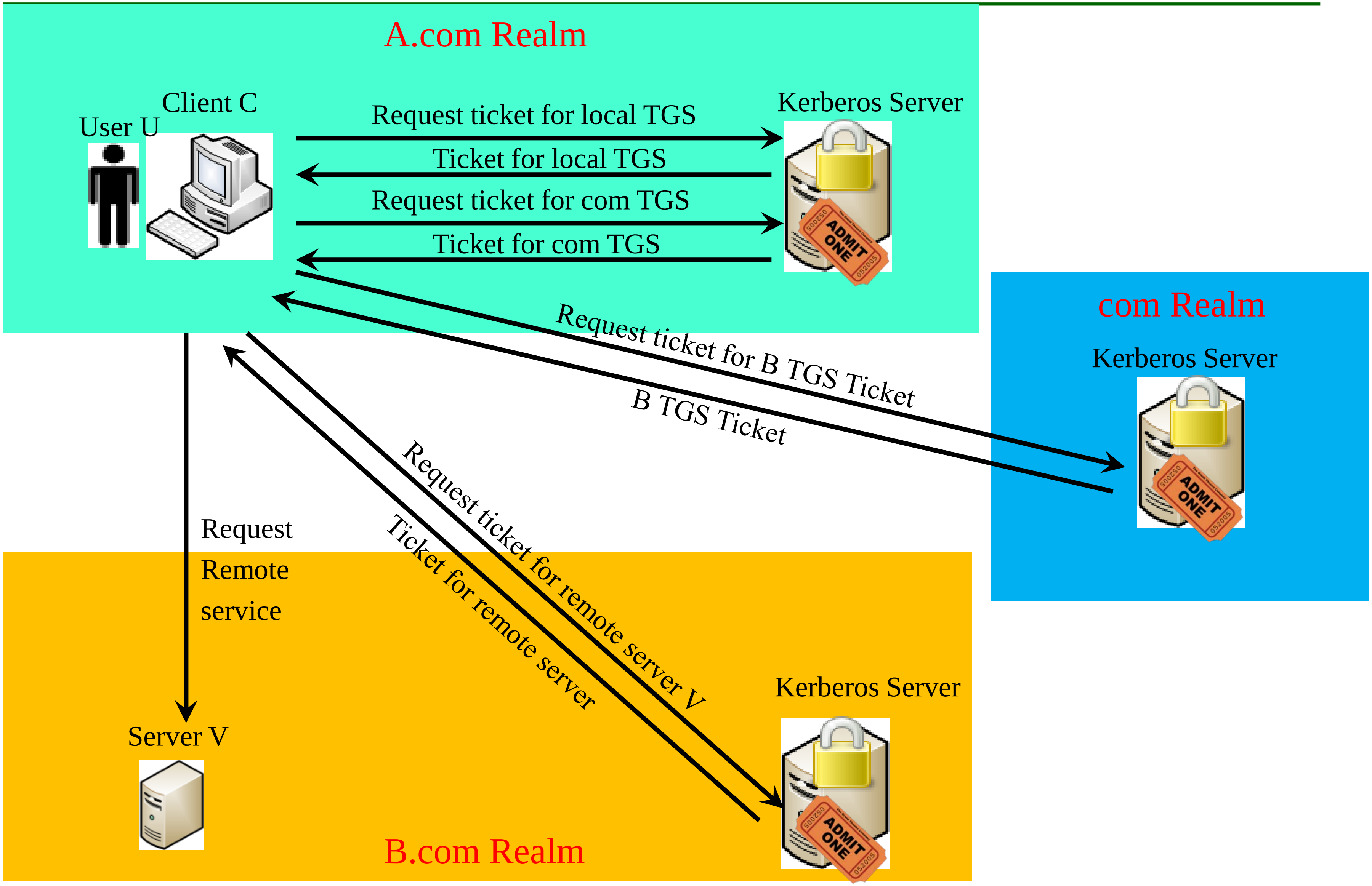


$\text{Options}|\{\text{Flags}|K_{C,\ V}|\text{Realm}_U|U|\text{Address}_C|\text{TimeSetting}\}_{K_V}$

$|\{U|\text{Realm}_U|TS_2|\text{Subkey}|\text{Seq\#}\}_{K_{C,\ V}}$

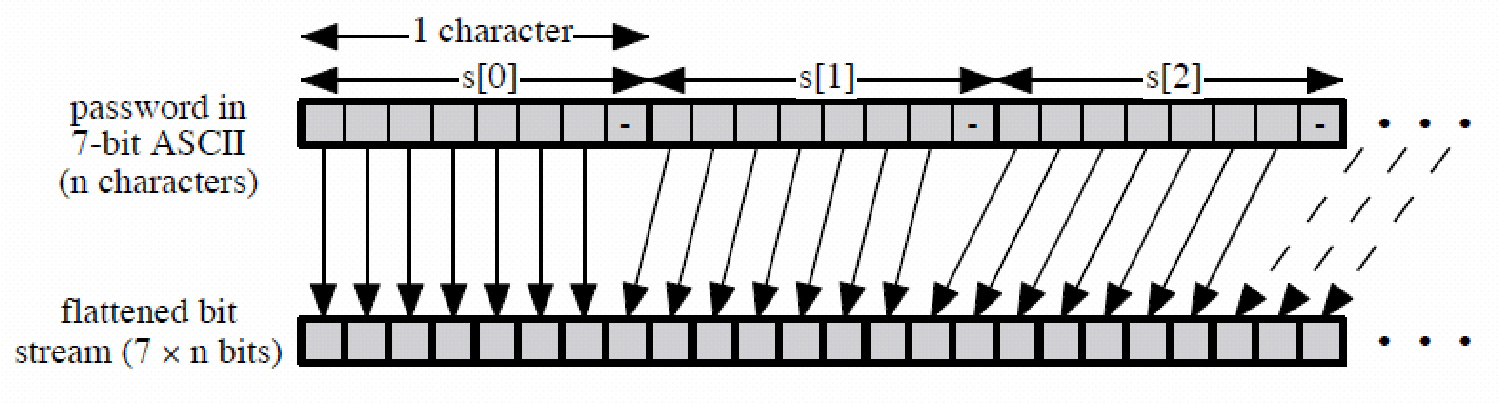
$\{TS_2|\text{Subkey}|\text{Seq\#}\}_{K_{C,\ V}}$

Kerberos: Version 5 (2/2)

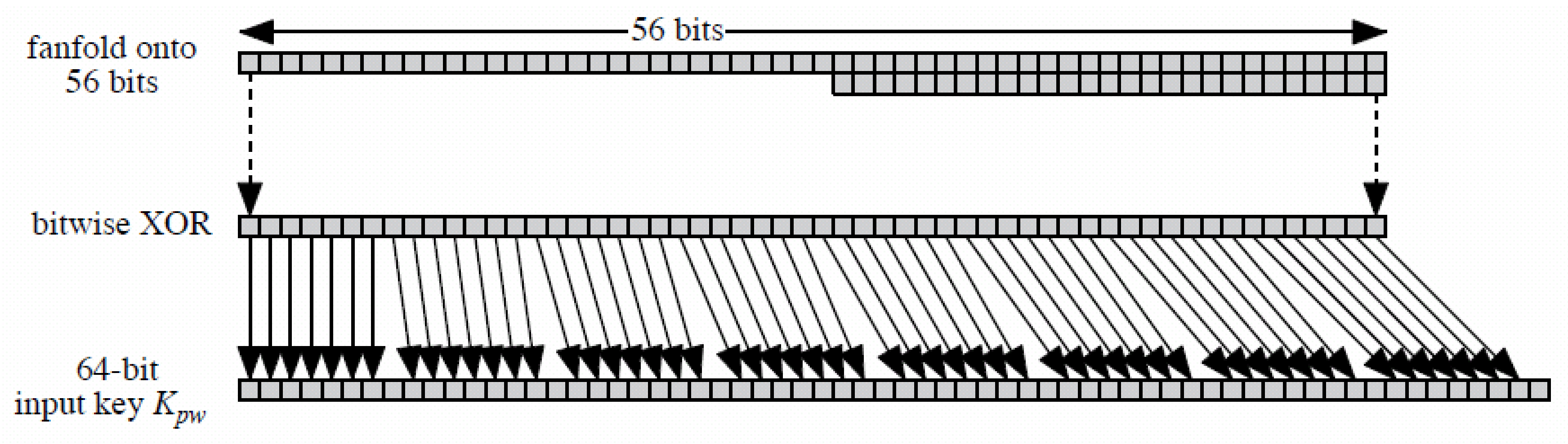


Password-to-Key transformation (1/2)

- Convert password to bit stream

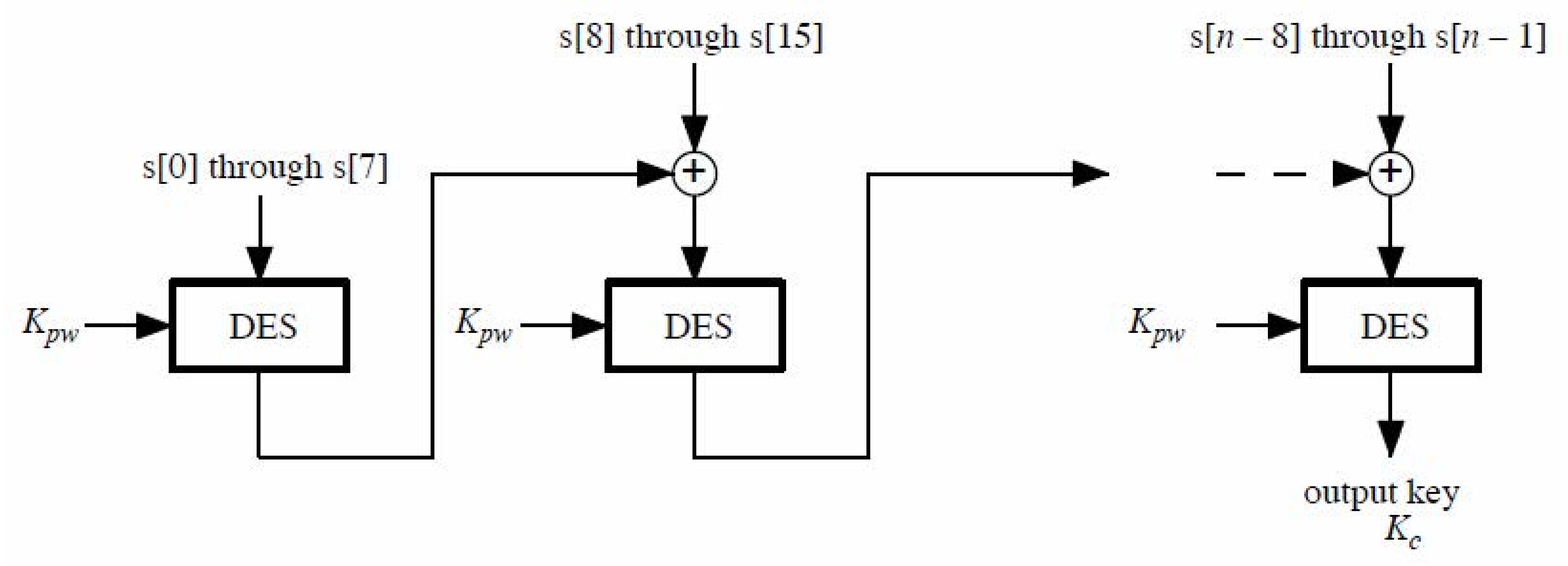


- Convert bit stream to input key

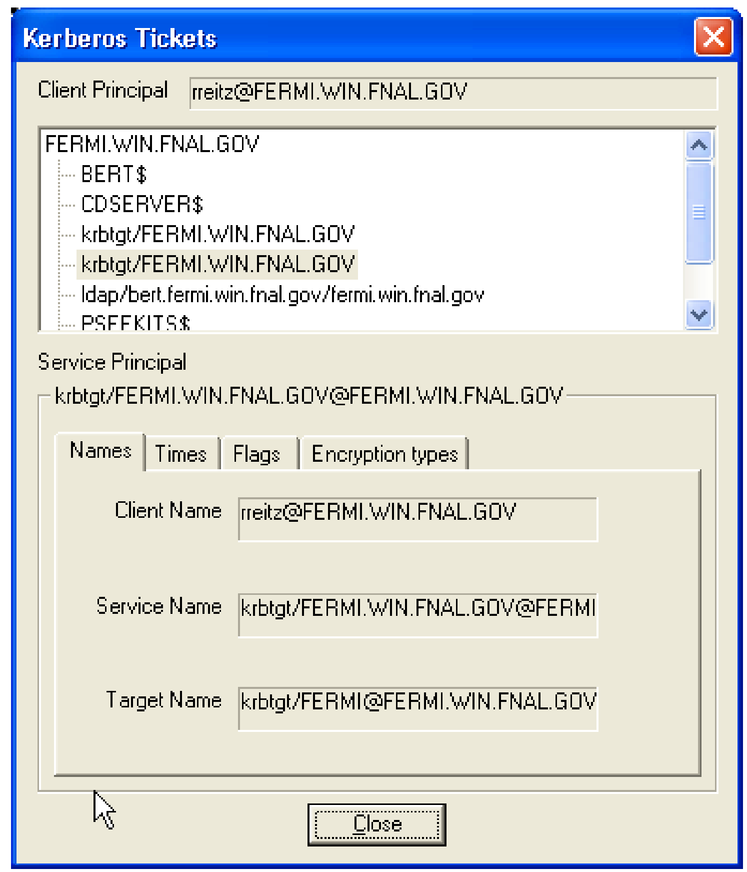


Password-to-Key transformation (2/2)

- Generate final key using DES in CBC mode



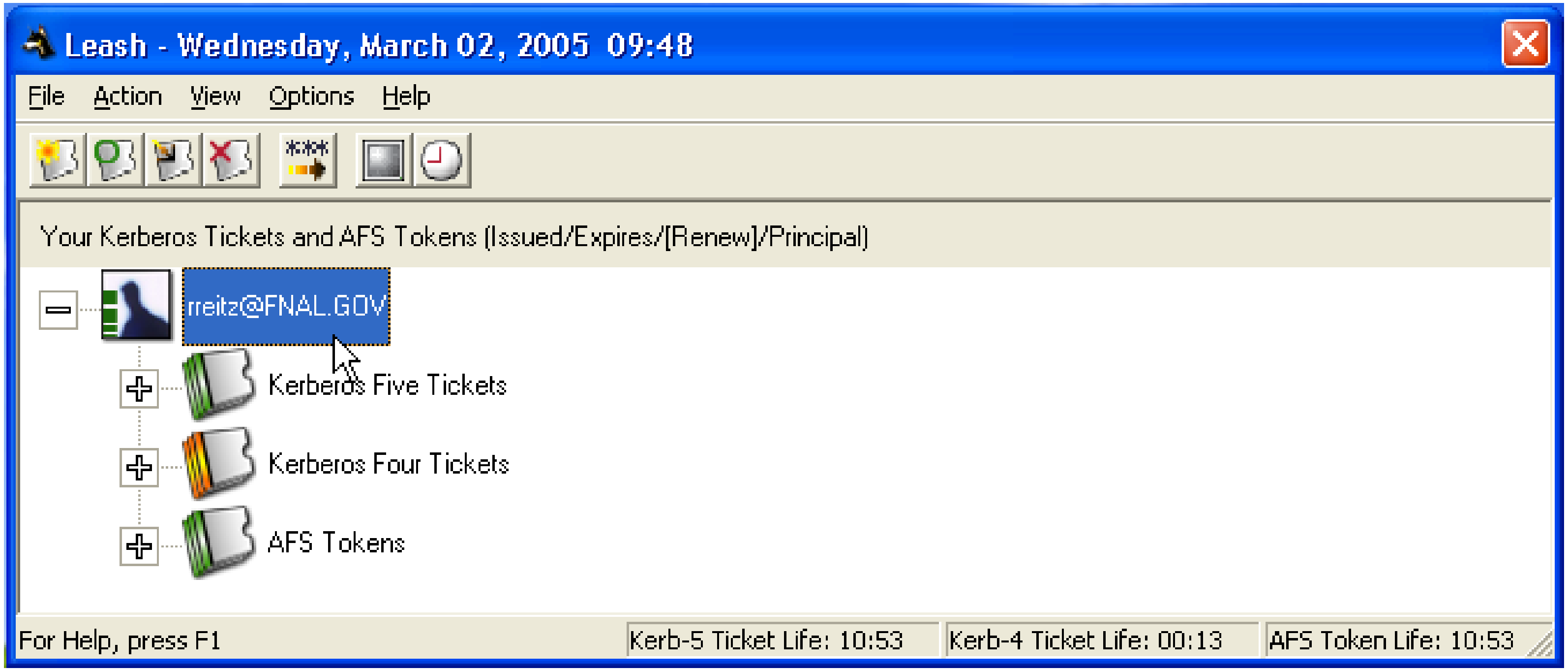
MS Windows



- Domain login
- Kerberos Ticket (Windows Kerbtray.exe application)
- Notice realm - FERMI.WIN.FNAL.GOV

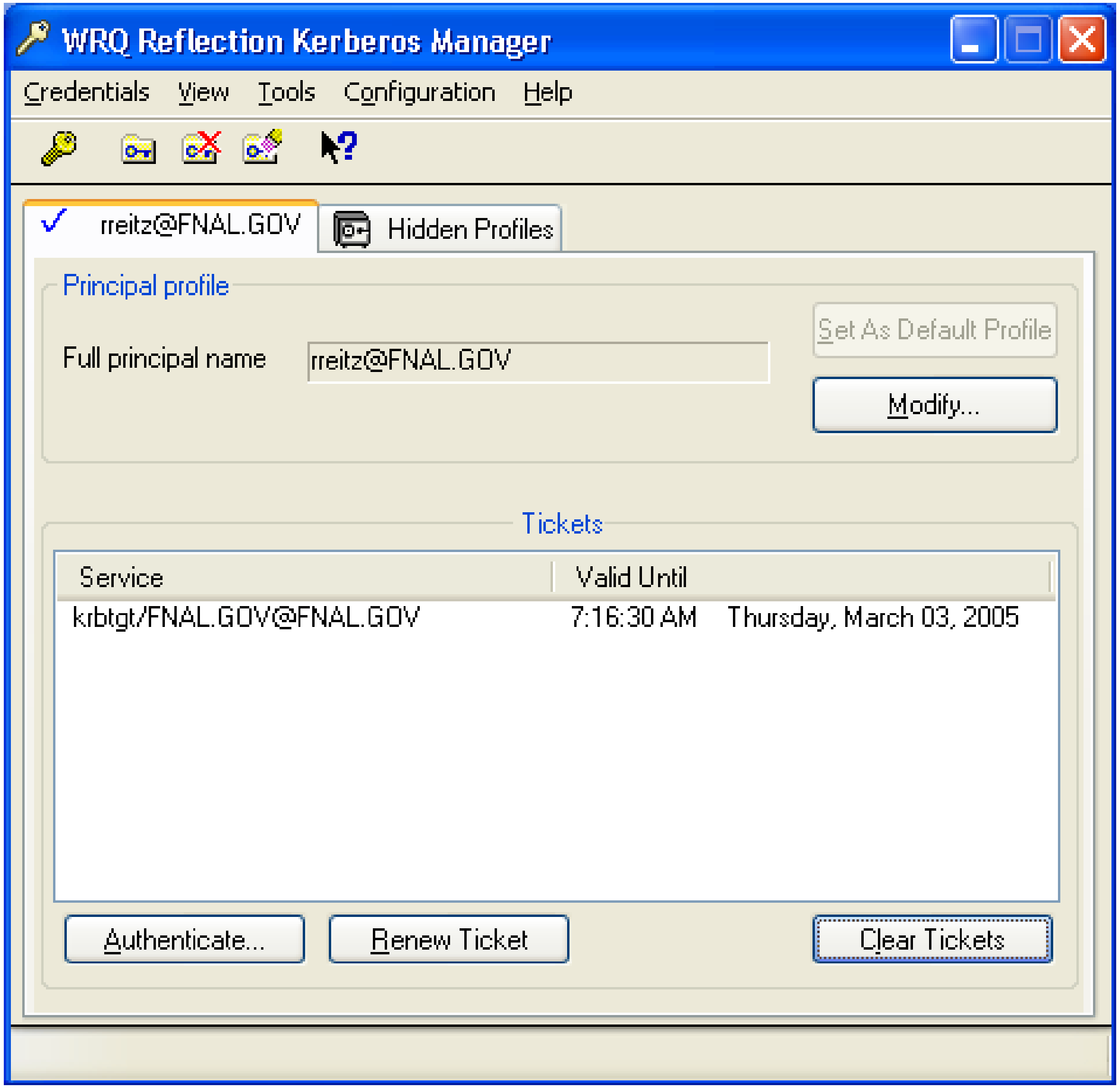
MS Windows Managing Credentials

- MIT Kerberos for Windows (KfW)
  http://web.mit.edu/kerberos/
- Notice realm - FNAL.GOV



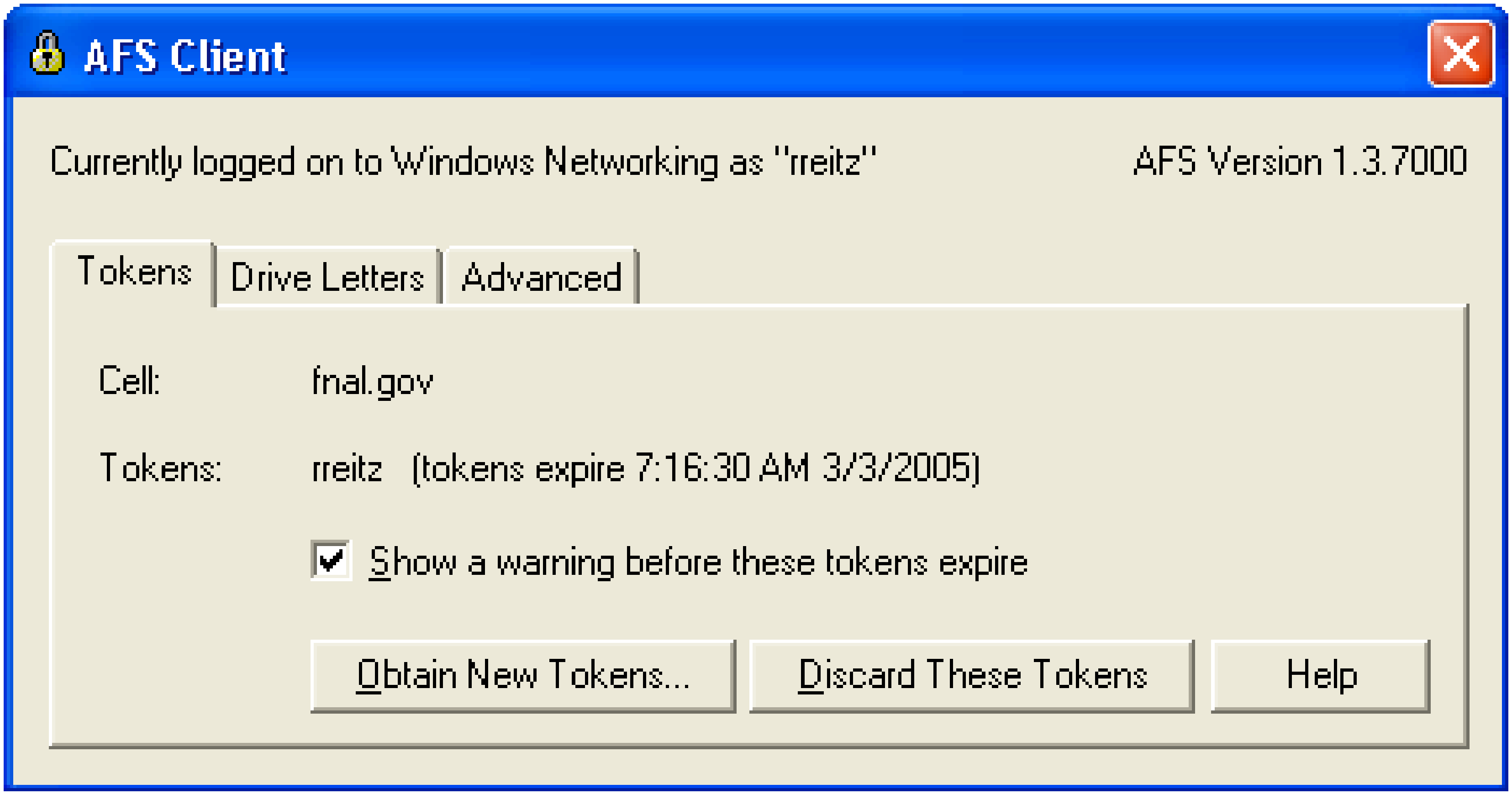
MS Windows Managing Credentials

- WRQ Kerberos Manager



MS Windows Managing Credentials

- OpenAFS Token



UNIX, Linux, Mac OS X

- Kerberos tools:
  - kinit
  - klist
  - kdestroy
  - k5push
- Clients:
  - telnet, ssh, ftp
  - rlogin, rsh, rcp

```
Last login: Wed Mar  2 08:23:53 on console
Welcome to Darwin!
[rreitz@brevix rreitz]$ kinit
Please enter the password for rreitz@FNAL.GOV:
[rreitz@brevix rreitz]$ klist -f
Kerberos 5 ticket cache: 'API:Initial default ccache'
Default Principal: rreitz@FNAL.GOV
Valid Starting     Expires            Service Principal
03/02/05 13:53:15  03/03/05 15:53:14  krbtgt/FNAL.GOV@FNAL.GOV
        renew until 03/09/05 13:53:14, FPRIA

[rreitz@brevix rreitz]$ ssh fenris
Last login: Sun Jan 23 20:48:37 2005 from ppp-68-251-44-22.dsl.chcgil.ameritech.
net
                              NOTICE TO USERS
[rreitz@fenris rreitz]$ klist -f
Ticket cache: /tmp/krb5cc_3819_5Zmg4N
Default principal: rreitz@FNAL.GOV

Valid starting     Expires            Service principal
03/02/05 14:54:21  03/03/05 15:53:14  krbtgt/FNAL.GOV@FNAL.GOV
        renew until 03/09/05 13:53:14, Flags: FfPRA
03/02/05 14:54:21  03/03/05 15:53:14  afs@FNAL.GOV
        renew until 03/09/05 13:53:14, Flags: FfPRA
[rreitz@fenris rreitz]$ 
```