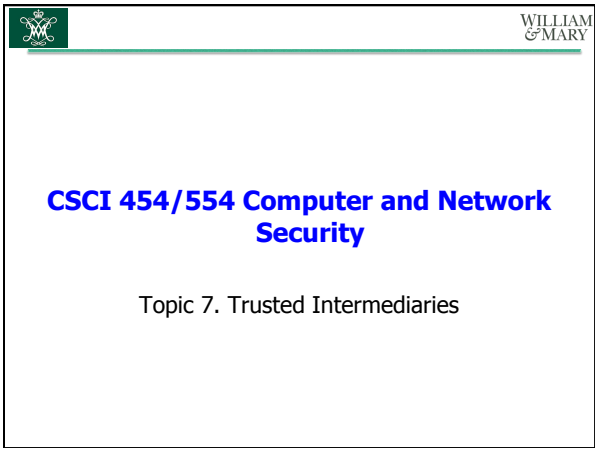

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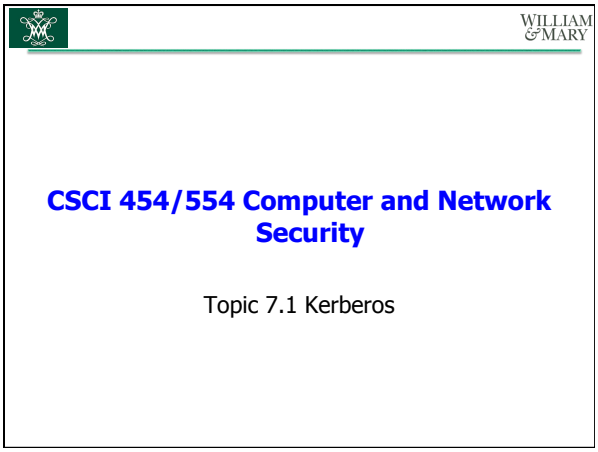
CSCI 454/554 Computer and Network Security

Topic 7. Trusted Intermediaries

Trusted Intermediaries

- Problem: authentication for large networks
- Solution #1
  - Key Distribution Center (KDC)
    - Representative solution: Kerberos
  - Based on secret key cryptography
- Solution #2
  - Public Key Infrastructure (PKI)
  - Based on public key cryptography



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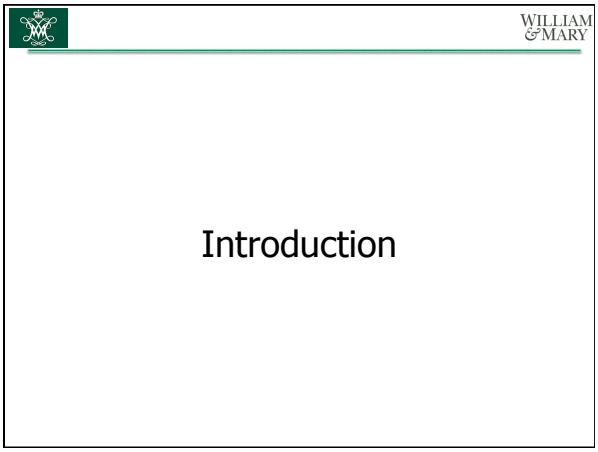
Topic 7.1 Kerberos

Outline

- Introduction
- Version 4: Basics
- Additional Capabilities
- Version 5 and Inter-Realm Authentication



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Introduction

Goals of Kerberos

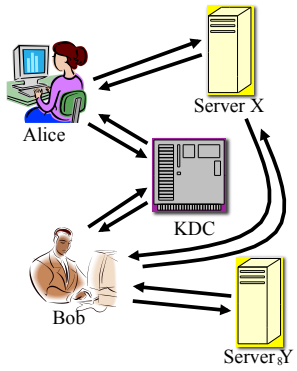
1. User ↔ server mutual authentication
2. Users should only need to authenticate once to obtain services from multiple servers
3. Should scale to large numbers of users and servers
   - makes use of a Key Distribution Center so servers don't need to store information about users

Some Properties

- Kerberos uses only secret key (symmetric) encryption
  - originally, only DES, but now 3DES and AES as well
- A *stateless* protocol
  - KDCs do not need to remember what messages have previously been generated or exchanged
  - the state of the protocol negotiation is contained in the message contents

Example Scenario

- Alice wants to make use of services from X, contacts the KDC to authenticate, gets ticket to present to X
- Bob wants to make use of services from X and Y, contacts the KDC, gets tickets to present to X and Y



The KDC

- Infrastructure needed (KDC components)
  1. the database of user information (IDs, password hash, shared secret key, etc.)
  2. an authentication server (AS)
  3. a ticket-granting server (TGS)
- The KDC of course is critical and should be carefully guarded

Secrets Managed by the KDC

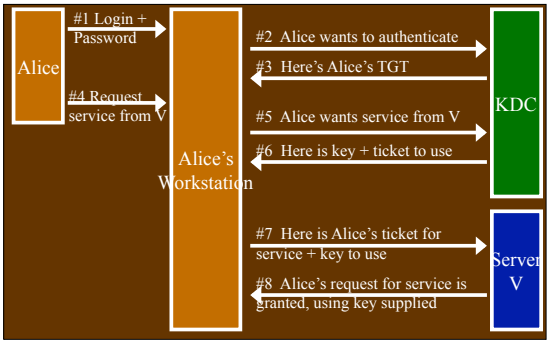
- A *personal* key used for encrypting/ decrypting the database, and for enciphering / deciphering message contents it sends to itself!
- A *master* (semi-permanent) shared key for each user
- a master shared key for each server

Passwords and Tickets

1. Alice provides a password when she logs into her workstation
2. Alice's workstation…
   - derives Alice's master key from the password
   - asks the KDC for a temporary session key K_A
3. The KDC provides a *ticket-granting ticket* (TGT) for Alice to use; eliminates need for…
   - …repeated authentication
   - …further use of master key

Basics of the Kerberos v4 Standard

Protocol Sketch (Common Case)



Msg#1: Enter Password

#1 A→W: "Alice" | password

- Alice types in her user ID and password in unencrypted form into her workstation

Msg#2: Request for Authentication

#2. W→KDC: $ID_A \mid TS_2 \mid ID_{KDC}$

- Workstation sends a message to KDC with Alice's ID (in unencrypted form)
- Many of these messages contain timestamps, for a) liveness, and b) anti-replay
- ID includes name and realm (see later)

Msg#3: Authentication Success

#3. KDC→W:

$K_{A\text{-}KDC}(ID_A \mid TS_3 \mid Lifetime_3 \mid \mathcal{K}_{A\text{-}KDC} \mid ID_{KDC} \mid TGT)$

- KDC sends Alice's workstation a session key and a TGT
  - encrypted with the master key shared between Alice and the KDC
- $\mathbf{K_{A\text{-}KDC}}$ is derived from Alice's password, used to decrypt session key $\mathcal{K}_{A\text{-}KDC}$

Msg#3: … (cont'd)

$K_{KDC}(ID_A \mid Addr_A \mid \mathcal{K}_{A\text{-}KDC} \mid Lifetime_{TGT} \mid TS_{TGT} \mid ID_{KDC})$

- The TGT is what allows the KDC to be stateless
  - means simpler, more robust KDC design
  - allows replicated KDCs (see later)
- The TGT contains
  - the session key to be used henceforth
  - the user ID (Alice)
  - the valid lifetime for the TGT

Msg#4: Alice Requests Service V

#4 A→W: ReqServ(V)

- Alice enters (to workstation) a request to access the service provided by V

Msg#5: Workstation Request Service V

#5 W→KDC:

$TGT \mid authenticator_5 \mid TS_5 \mid Lifetime_5 \mid ID_V$

- Workstation sends to the KDC…
  - the TGT previously granted (proves Alice's identity)
  - the server she wishes to request service from
  - an authenticator for this message

Msg#5… (cont'd)

$\mathcal{K}_{A\text{-}KDC}(ID_A \mid TS_{auth5})$

- The authenticator is an encrypted timestamp
  - why needed?
  - (reminder: timestamps requires user and KDC clocks to be loosely synchronized)

Msg#6: KDC Generates Ticket

#6 KDC→W:

$\mathcal{K}_{A\text{-}KDC}(ID_A \mid TS_6 \mid Lifetime_6 \mid \mathcal{K}_{A\text{-}V} \mid ID_V \mid TKT_V)$

- KDC decrypts the TGT and…
  - checks that lifetime has not expired
  - gets the shared key $\mathcal{K}_{A\text{-}KDC}$
- KDC sends back to workstation
  - identity of the server
  - a shared key ($\mathcal{K}_{A\text{-}V}$) for Alice and the server
  - a ticket for Alice to present to V

Msg#6… (cont'd)

$K_{V\text{-}KDC}(ID_A \mid Addr_A \mid \mathcal{K}_{A\text{-}V} \mid Lifetime_{TKT} \mid TS_{TKT} \mid ID_V)$

- The ticket contains
  - ID of the initiating user
  - shared key $\mathcal{K}_{A\text{-}V}$
  - lifetime of the ticket

Msg#7: Workstation Contacts Server

#7 W→V: $ID_V \mid TKT_V \mid authenticator_7$

- Message contains
  - ticket (from the KDC)
  - authenticator
- If server V is replicated, ticket can be used with each server to receive service

Msg#7… (cont'd)

$\mathcal{K}_{A\text{-}V}(ID_A \mid Chksum_{auth7} \mid TS_{auth7})$

- Authenticator is valid for 5 minutes
  - loose synchronization required
  - replay attack possible for short period if server does not store previous authenticators

Msg#8: Server Authenticates to Alice

#8 V→W : $\mathcal{K}_{A\text{-}V}(Chksum_{auth7} + 1)$

- Reply to Alice's workstation contains
  - timestamp sent by Alice, incremented by 1

Done!

1. Alice has authenticated to KDC (which is trusted by server)
2. Server has authenticated to Alice
3. A session key has been negotiated, for encryption, message authentication, or both (but see previous discussions)

Additional Capabilities

Key Updates

- Users will need to change their keys periodically, as do servers
- Implication: outstanding tickets (based on old keys) must be invalidated, and new ones issued
  - how find all those old tickets and recall them?
- Alternative: allow key *versions*
  - key version number to use is included in messages
  - KDCs and servers must allow overlap of old keys and new keys, allow time for use of old keys to age out

KDC Replication

- A good strategy: allow multiple KDCs for a single domain (availability, fault tolerance)
- Issue: how keep the KDC databases consistent?
  - one database copy is the master; all updates are first made to that
  - this master DB is copied (downloaded) to the other KDCs, either periodically, or on demand
  - the transfer is authenticated

Adding Network Addresses to Tickets

- Add IP addresses (in addition to user IDs) to tickets
  - must match Source IP address in the packet containing the ticket, or message is rejected
  - just one more piece of information to make attacks harder (not foolproof, spoofing IP addresses is relatively easy)
- Problems
  - NATs will change IP addresses in packet headers but not in tickets
  - prevents delegating access rights (i.e., a ticket) to a user at another location

Specification of Messages

- See the text, or RFC, for full details

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Kerberos v5 + Interrealm Authentication

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Some Differences with v4

1. v5 uses ASN.1 syntax to represent messages
   - a standardized syntax, not particularly easy to read
   - but, very flexible (optional fields, variable field lengths, extensible value sets, …)
2. v5 extends the set of encryption algorithms
3. v5 supports much longer ticket lifetimes
4. v5 allows "Pre-authentication" to thwart password attacks
5. v5 allows delegation of user access / rights

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Delegation

- Giving someone else the right to access your services
  - how is that useful?
- Some not-so-good ways to implement
  - give someone else your password / key
  - give someone else your tickets (TKT_V's)
- Kerberos v5 provides 3 better choices

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Delegation… (cont'd)

- Choice #1: Alice asks the KDC to issue a TGT with Bob's network address
  - she then passes this TGT and the corresponding session key to Bob
  - in effect, she tells the KDC she will be delegating this access right
- Choice #2: Alice asks the KDC to issue a TGT directly to Bob, with Bob's address
  - even better, although now the KDC is required to contact Bob directly

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Delegation… (cont'd)

- Choice #3: Alice gets a TGT, gives it to Bob
  - along with authorization data that will be passed to the application service, and must be interpreted by the application

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Transitive Delegation

- Alice delegates to Bob who delegates to Carol who…
- TGTs (for arbitrary service) can be transitively delegated if marked as "forwardable"
- Tickets (providing access to a specific service) can be transitively delegated if marked as "proxiable"
- Servers are not obligated to honor such requests for transitive delegation

Pre-Authentication

#3. KDC→W: $K_{A\text{-}KDC}(ID_A \mid TS_1 \mid Lifetime_1 \mid \mathcal{X}_{A\text{-}KDC} \mid ID_{KDC} \mid TGT)$

- Reminder: Msg #3 is encrypted by the KDC with $\mathbf{K_{A\text{-}KDC}}$
  - could be used by adversary to mount a password- or key-guessing attack
- Solution: before Msg #2, require Alice to send *pre-authentication data* to the KDC
  - i.e., a timestamp encrypted with the shared master key
  - this proves Alice knows the key

Pre-Authentication (Cont'd)

$K_{V\text{-}KDC}(ID_A \mid Addr_A \mid \mathcal{X}_{A\text{-}V} \mid Lifetime_5 \mid TS_5 \mid ID_V)$

- Msg#6 still provides an opportunity for Alice to mount a password-guessing attack against the server key $\mathbf{K_{V\text{-}KDC}}$
  - solution: servers are not allowed to generate keys based on (weak) passwords

Renewable Tickets

- Tickets in v5 can be valid for a long time, but have to be renewed periodically, by contacting the KDC
- Each ticket contains
  - authorization time
  - start (valid) and end (expiration) times
  - renew-until (latest possible valid) time
- Newly-issued (renewed) tickets will have a new session key

Renewable… (cont'd)

- Tickets can also be *postdated* – valid in the future
- An expired ticket cannot be renewed

Cryptographic Algorithms in v5

- Message integrity only
  - MD5 + encrypt result with DES using shared secret key
  - use DES residue
  - + others
- Encryption + integrity
  - basic = DES/CBC with a CRC
  - extended: 3DES + HMAC/SHA1
  - recently: AES/CBC + HMAC/SHA1
- Note: secret key only

"Sub-Session" Keys

- Alice may wish to use different keys for different conversations/connections with the same server
  - why?
- This is made possible by including in the authenticator of Msg #7 a subkey to use just for this connection

$\mathcal{K}_{A-}(ID_A \mid TS_{auth7})$

expanded to…

$\mathcal{K}_{A-}(ID_A \mid TS_{auth7} \mid subkey)$

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v5 Messages

- See text or RFC for lots of details, and specifications of message formats and contents…
- RFC4210 Kerberos v5

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Realms

- A *realm* is a group of resources sharing a single authority for authorization
  - frequently the same as a DNS domain, and referred to by the domain name (e.g., "wm.edu")
- A realm consists of…
  1. KDC (TGS, AS, and database)
  2. users
  3. servers

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Inter-Realm Authentication

- What if a user wants access to services located in a different realm?
- Simple solution: require Alice to be registered in each realm, has to undergo separate authentication in each
- More complex solution: the KDCs cooperate to perform inter-realm authentication
  - these KDCs must have previously-negotiated shared secret keys
  - receiving KDC can decide for itself whether to accept credentials issued by another KDC

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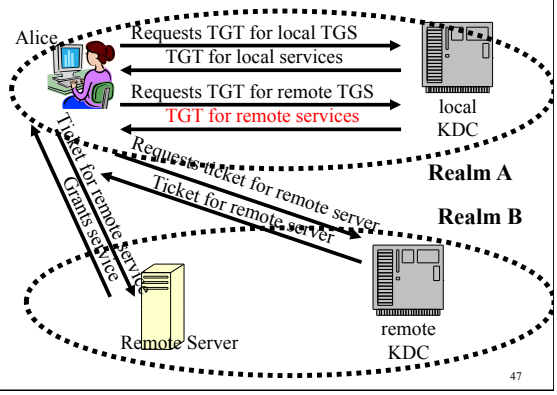
Example



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Inter-Realm… (cont'd)

- A complex extension is the notion of inter-realm paths (> 2 KDCs cooperating)
- How find a path of cooperating KDCs to a target?
  - typical solution: hierarchy of KDCs (only one possible path)
- A ticket will contain the path of realms traversed by this ticket
  - the server receiving the ticket can decide if each of those realms is trustworthy, in order to accept or reject the ticket

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Summary

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1. Kerberos is the most widely used authentication service
2. Modeled on the Needham-Schroeder protocol, but adds the TGT
3. v5 extends and fixes problems of v4; v4 no longer in active use
4. Inter-realm authentication scales to very large systems (e.g., the Internet)

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