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SECURE DEPLOYMENT STORY FOR CHALLENGING ENVIRONMENTS

Bachelor's Thesis
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ABSTRACT

- **FIXME: remove this list**
- **Background information (present tense)**
- **Principal activity (past tense/present perfect tense)**
- **Methodology (past tense)**
- **Results (past tense)**
- **Conclusions (present tense/tentative verbs/modal auxiliaries)**

Network based automatic installation of operating system is and has been a crucial method to manage masses of computers. Protecting every step of the installation is important to be able to trust that the network installation system completed the installation so that the operating system and configuration is what the user wanted.

This thesis reviews history and current state of network based automatic installation systems based on what protocols do they use. Then it continues to identify risks to those protocols and see how the situation could be improved by using cryptography using Transport Layer Security (TLS) protocol and digital signatures.

Proof of concept implementation using TLS and digital signatures is compared to two other installation systems.

Keywords: sample, keywords

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TIIVISTELMÄ

FIXME Esimerkkitiivistelmä

Avainsanat: esimerkki, sanoja

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FOREWORD

FIXME FOREWORD

This LaTeX-template has been used by various people at department since the late 1990's, and has slowly improved over time. It is still somewhat rough at the edges, but hopefully will be helpful in reducing some of the pain involved in writing a diploma thesis.

Contributors to the template include Mika Korhonen (original author), Pekka Pietikäinen, Christian Wieser and Teemu Tokola. If you make any improvements to this template, please contact ouspg@ee.oulu.fi, and we will try to include them in further revisions.

The template was updated during the summer of 2013 by Juha Kylmänen.

ABBREVIATIONS

BOOTP	Bootstrap Protocol (IETF)
CIA	Confidentiality, Integrity, Availability
DHCP	Dynamic Host Configuration Protocol (IETF)
DNS	Domain Name System (IETF)
DNSSEC	Domain Name System Security Extensions (IETF)
FTP	File Transfer Protocol (IETF)
GPG	The GNU Privacy Guard
HTTP	Hypertext Transfer Protocol (IETF)
HTTPS	HTTP over TLS
IETF	Internet Engineering Task Force
IP	Internet protocol (IETF)
MitM	Man In The Middle
NFS	Network File System (IETF)
NSA	National Security Agency
PXE	Preboot Execution Environment
RARP	A Reverse Address Resolution Protocol (IETF)
RFC	Request for Comments
TFTP	Trivial File Transfer Protocol (IETF)
TLS	Transport Layer Security (IETF)
UDP	User Datagram Protocol (IETF)
URL	Uniform Resource Locator
USB	Universal Serial Bus
USENIX	The Advanced Computing Systems Association
initrd	initial ramdisk

1. INTRODUCTION

Loading operating system into computer remotely over network (“network booting”, “diskless booting”) has been used for decades. Network booting can be used to bootstrap operating system installation (“network installation”) or it could be used for diskless nodes to load the operating system and run it using disk provided by server.

Usually network installation systems are built to serve single organization (e.g. single business) inside their own networks (business intranet) to achieve repeatable and homogeneous installations. Installation preferably is expected be as easy and as fast as possible.

Many Linux distributions offer “net install” which is a small image used to boot the computer into a state where rest of the installation software and packages can be downloaded directly from Internet. After downloading files the installer is executed. It runs a set of steps and finally a fresh operating system installation is completed on the computer.

This thesis has four parts. Introduction looks at history and current state of installation systems (how it has been done in the past and how it works currently), then identifies what network based risks there are to installation system. Next chapter contains design principles of proof of concept installation system which tries to mitigate against some identified risks discussed. Then the proof of concept implementation is compared against two other installation systems. And finally in conclusions and discussion chapter the findings are summarized and recommendations are given for new research and how security of installation systems could be improved further.

The work done is a practical hands on study of how installation systems work and how to improve the security of these systems.

1.1. Involved Protocols

Multiple network protocols have been developed and used to allow booting using IP network. Early published standards include RARP (“A Reverse Address Resolution Protocol”, RFC903, published 1984 [1]) and BOOTP (“Bootstrap Protocol”, RFC951, published 1985 [2]) which could be used to allow “a diskless client machine to discover its own IP address” [2], TFTP (“Trivial File Transfer Protocol”, RFC783, published 1981 [3]) “may be used to move files between machines on different networks implementing UDP.” [3].

Later developments include RARP and BOOTP to be superseded by DHCP (“Dynamic Host Configuration Protocol”, RFC1531, published 1993 [4]) and TFTP superseded by NFS (“Network File System”, RFC1094, published 1989 [5]) which “provides transparent remote access to shared files across networks.” [5] PXE (“Preboot Execution Environment” [6]) is specification from Intel Corporation to standardize preboot environment for network booting. In some cases TFTP or NFS or both can be replaced with HTTP (“Hypertext Transfer Protocol” [7][8]).

1.2. Current state

FIXME: what is different in the cloud to earlier installs?

Software deployment technologies [9], securing virtual machines [10] as well as cloud computing security challenges [11][12] have been widely studied. However, network installation of operating system is still much the same as in the 1980s and it's the base for any software deployment or virtual machine installation to get operating system installed securely.

FIXME: Why Alpine?

Alpine Linux's PXE Boot HOWTO [13] summarizes the current situation:

> Alpine can be PXE booted starting with Alpine 2.6-rc2. In order to accomplish this you must complete the following steps:
>
> 1. Set up a DHCP server and configure it to support PXE boot.
> 2. Set up a TFTP server to serve the PXE boot loader.
> 3. Set up an HTTP server to serve the rest of the boot files.
> 4. Set up an NFS server from which Alpine can load kernel modules.
> 5. Configure mkinitfs to generate a PXE-bootable initrd.

As we can see, the whole process still relies on old protocols DHCP, TFTP, HTTP and NFS developed around 1980–1990. However, these protocols provide no security and should not be used in networks.

TFTP, NFS and HTTP protocols could be replaced with HTTPS (HTTP over TLS) where TLS (Transport Layer Security Protocol [14]) provides communications security using cryptography and authentication of one or both communicating parties.

DHCP is de facto standard to achieve zero configuration (FIXME: what's zeroconfig? explain) and it's difficult to replace so it's shortcomings need to be countered with other protocols.

Also, DNS (Domain Name System, RFC1035 [15]) is a vital protocol to the internet. It provides translation from name to IP addresses and back (and other name services). DNS is also de facto standard. Work to protect DNS traffic has been done (DNSSEC, RFC4035 [16]) and DNSSEC is slowly getting a foothold to protect DNS communications, but for installation system it's possible to continue using DNS and use other means to verify DNS is working as it should.

Shortcomings of all these protocols and how to mitigate against the risks are discussed later.

1.3. Challenging environments

Computer networks are not safe nor secure. Internet being the most unsafe of networks. Connections in the internet do not see national borders and travel through different areas of laws and regulations. Protocol packets are passed from one internet service provider to another. On every step of the connection someone might be listening or even altering the connection to ones own agendas. It might be governmental body

(like NSA's PRISM program [17]), criminal organization who have gained foothold on point of network or simply curious individual just being able to do so.

Same problems can also be present in networks like corporate intranets where both government and criminal organizations might have gained foothold to operate. In USENIX Enigma 2016 conference Rob Joyce, Chief of Tailored Access Operations in National Security Agency [18] describes how his team infiltrates networks and moves there laterally to gain what they are after. Therefore intranets should be treated with same level of mistrust as internet.

1.4. Risks

CIA triad divides network security into three elements: confidentiality, integrity and availability.

Confidentiality means that the sender of the message encrypts the content so only a receiver with correct key can decrypt the content and see the message. Confidentiality can be achieved in network security for example by using TLS protocol [14] to encrypt network traffic.

Integrity control guarantees that the message cannot be modified during transfer. It consist two parts: Non-repudiation and authenticity.

Non-repudiation ensures proof of integrity and the origin of data. This is usually achieved with using authentication and integrity control. Digital signatures [19][20] can provide non-repudiation of messages. Standards such as S/MIME [21] or OpenPGP [22] can be used for digital signature format.

Authenticity ensures receiving, transmitting or both parties determine they are communicating with intended party before exchanging any confidential messages. TLS protocol provides means to verify authenticity of communicating parties.

Availability means that the systems are up and operational. Perfect security could be achieved by turning everything off, but usability would be zero. It's important to ensure availability so that network services can be used. Availability can be achieved by allocating enough human and computing resources to operate the services.

Risks can be identified in all components from hardware to operating system vulnerabilities. Table 1 lists some common known attacks which could be targeted towards network booting or network installation systems.

Component	Role	Risks
HTTP	File transfer	confidentiality, integrity
DNS	Name service	non-repudiation
NFS	File transfer	confidentiality, integrity
TFTP	File transfer	confidentiality, integrity
DHCP	Zero configuration	non-repudiation

Table 1. Roles and risks of various components used in operating system installation over network

DHCP and DNS protocols could be used to redirect (“hijack”) future communications into malicious services. DHCP is commonly used to assign IP address to client and give various information (TFTP server’s IP address, DNS servers’ IP addresses). Malicious DHCP could take over future TFTP and DNS communications. DNS has many uses, but commonly it’s used to translate host name into IP address. Malicious DNS server could redirect future communications into malicious services.

TFTP, NFS and HTTP protocols could be used to deliver malicious files which when executed in target system compromise the operating system installation or even infect the hardware the operation was performed in.

There has been development to secure DHCP and DNS. That however requires the network in question to be configured to take these security measurements in action. But the risks can be detected by other components (e.g. using TLS’s server authentication, and digital signatures) so there’s no need to changes to network configuration. Thus the installation can be done securely in any network and if something malicious is detected the installation process can halted.

Hardware (e.g. physical server or laptop) and peripherals (e.g. displays, keyboards, mice, removable medias) can have backdoored firmware. The backdoors could have been installed already on factory or firmware was infected with some malware previously ran on the machine. Discussing mitigations for risks against hardware is out of scope of this work.

1.5. Mitigation

Risks can be mitigated by using trusted media, secure communication channel and cryptographically signed files.

Boot environment is loaded from trusted media, for example using prebuilt USB mass media. This media contains software and files to safely load next steps required to load operating system kernel and other files safely over network.

Network communication is done using HTTPS with X.509 certificate pinning. This authenticates the remote server and makes it harder to MitM attack the connection. If secure channel can’t be established, the boot process should be halted.

Signed files are used to ensure authenticity of files used for booting. For example many Linux distribution mirrors only provide files via HTTP or FTP servers which are susceptible to MITM attack. If signature check fails the boot process should be halted.

2. IMPLEMENTING SECUDEP

To see if it's possible to use HTTPS and digital signatures, a simple implementation of installation system called *secudep* was implemented. Source code can be found from secudep's project site on GitHub [23].

Secudep's implementation has three main design principles: ease of use, ease of deploy and security. Deploying new installation system should be easy so that it encourages building small, easy to update and easy to maintain setups. Ease of deployment might also attract developing new use cases and applications on top of already existing system. With the implemented solution there should be no need to have monolithic and centralized installation infrastructure, but designs can shift more towards personal or per application installation infrastructure.

Installation infrastructure should help end user achieve fresh installation of operating system and applications as easily, smoothly and as fast as possible. Most of the decisions required for achieving installation should be made beforehand and automatized as much as feasible.

Security is more difficult design principle to tackle. For the installation infrastructure the concentration should be on selecting safe defaults and guide user to make safe choices.

This implementation borrows lots of ideas and lessons learned from boot.foo.sh[24] and from installation infrastructure used by Faculty of Information Technology and Electrical Engineering in University of Oulu. These two systems are also compared to this implementation in next chapter.

2.1. Tools

Secudep uses iPXE [25] as a network boot firmware. iPXE is PXE [6] implementation with additional features such as support for booting via HTTP [8] protocol. Support for HTTPS can also be compiled in. iPXE binary build is done using Docker [26] (FIXME: explain setup) software containerization platform to achieve repeatable builds with managed dependencies.

Python programming language, bash shell scripts and OpenSSL are used to build individual parts of the system.

2.2. Setting up installation system

Setting up installation system using secudep has the following steps:

1. Generate digital signing keys
2. Collect HTTP servers' X.509 certificates for public key pinning (FIXME: explain why, how)
3. Build iPXE bootable media
4. Write configuration file

5. Generate contents for deployment

Future work on secudep should simplify these steps even further. Digital signing keys could be automatically generated if missing, X.509 certificate collection could be automated based on secudep's configuration file. iPXE media build could also be done every time contents for deployment are generated.

2.3. Deploying

Everything needed for installation system to operate (from server side) are generated under one directory. This directory can then be published on HTTPS server. The URL for the installation system files is configured in secudep's configuration file.

2.4. Security

Secudep make it as easy as possible to use public key pinning for HTTPS hosts and digital signatures to verify authenticity of files.

iPXE is configured to require trusted files. File is trusted only after it's signature is verified successfully. This requirement can't be turned off once it's turned on.

3. COMPARISON BETWEEN SYSTEMS

3.1. Method

I studied three different implementations of installation infrastructure (later called "systems") by installing operating system using it and studying what protocols are used. Protocols were identified from network traffic capture using Wireshark network protocol analyzer. The operating system used for testing installation was CentOS Linux Distribution because it was available on all three systems.

First system was what I want to call "traditional" and is designed to be used inside corporate network. Second system is a more modern (boot.foo.sh [24]) designed to be used over the internet and then last one (secudep) was the implementation discussed in this thesis. The comparison analyzes protocols used to achieve the installation and doesn't go deeply into contents of the protocol messages and only cursorily looks at how protocols are used.

All three installations were done using VirtualBox virtual machines. VirtualBox allows network traffic to be captured from the beginning of virtual machine's lifetime. This allowed me to capture and study what happens with earliest stages of boot process.

3.2. Result

Step	traditional	over internet	secudep
Zero configuration	DHCP	DHCP	DHCP
Name resolution	DNS	DNS	DNS
Boot menu	TFTP	HTTP	HTTPS (DS)
Digital signatures	N/A	N/A	HTTPS
kernel and initrd	TFTP	HTTP	HTTP (DS)
Kickstart	NFS	HTTP	HTTPS
Installation files	NFS (DS)	HTTP (DS)	HTTP (DS)

Table 2. Comparison between how three different installation infrastructures use protocols. DS in table means Digital Signatures.

Summary of the protocols used in various steps of installation process can be found from Table 2.

I identified and named common steps each system used to achieve the installation. The steps were "zero configuration", "name resolution", "boot menu", "kernel and initrd", "kickstart" and "installation files". Secudep also has additional step "digital signatures".

"Zero configuration" is the first step and it's purpose was to get IP address and DNS server addresses for system to be installed.

"Name resolution" is used to translate host names into IP address to communicate with other servers.

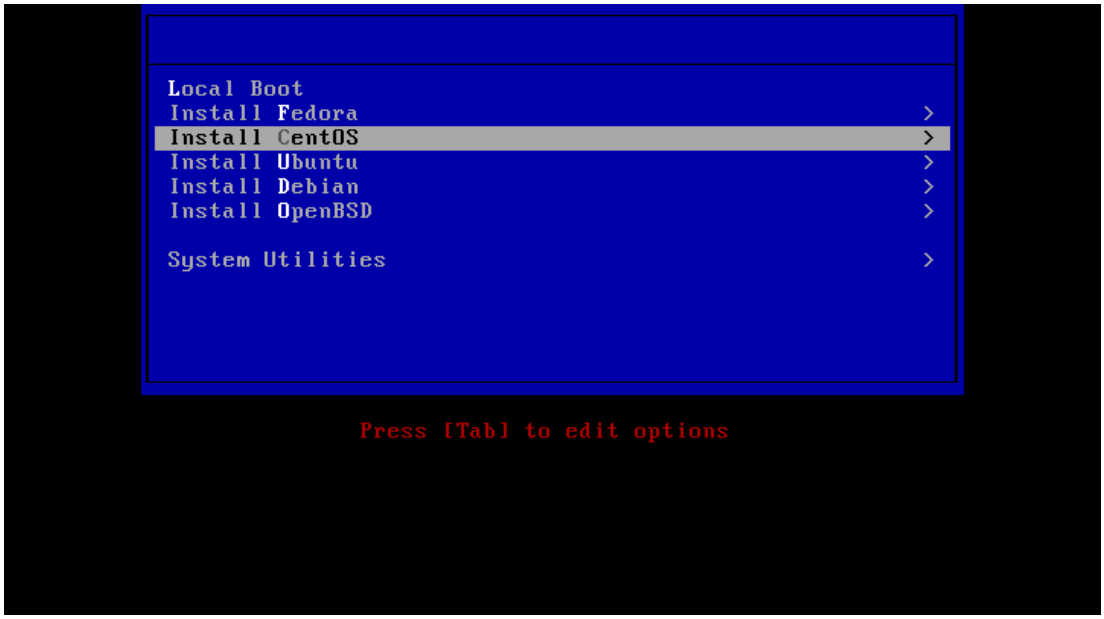

Figure 1. boot.foo.sh boot menu showing selection of operating systems.

"Boot menu" is used to display choices of operating systems to be installed. Example of boot menu can be seen in figure 1.

"kernel and initrd" are the files needed to launch Linux installation. These two files are downloaded over the internet and then kernel is executed and it continues the boot process.

"Kickstart" is CentOS specific file for automating unattended installation. It's set of instructions downloaded and executed by the installation process.

"Installation files" are the contents of operating system to be installed. The files are downloaded and extracted to hard drive to achieve the installation.

"Digital signatures" are cryptographically calculated proofs to verify signed content (for example contents of a file). If the content is changed, the signature check fails and user can be alerted about the incident.

3.3. Analysis of Results

In all three systems the same protocols are used for zero configuration (DHCP) and name resolution (DNS). DHCP and DNS are de facto standard protocols to achieve the task they solve so there's no surprise here.

Boot menu is used to display choices of operating systems to be installed. TFTP and HTTP are the protocols used in traditional and over the internet systems. Both TFTP and HTTP protocols are susceptible to Man in the Middle attack. Secudep uses HTTPS (HTTP over TLS) with signed files.

Only secudep uses digital signatures and the signature files are fetched over HTTPS. This is the step missing from the traditional and over the internet installation systems. Figure 2 shows how secudep's process is halted when the digital signature verification fails. This failure is a clear indication that something is definitely wrong.

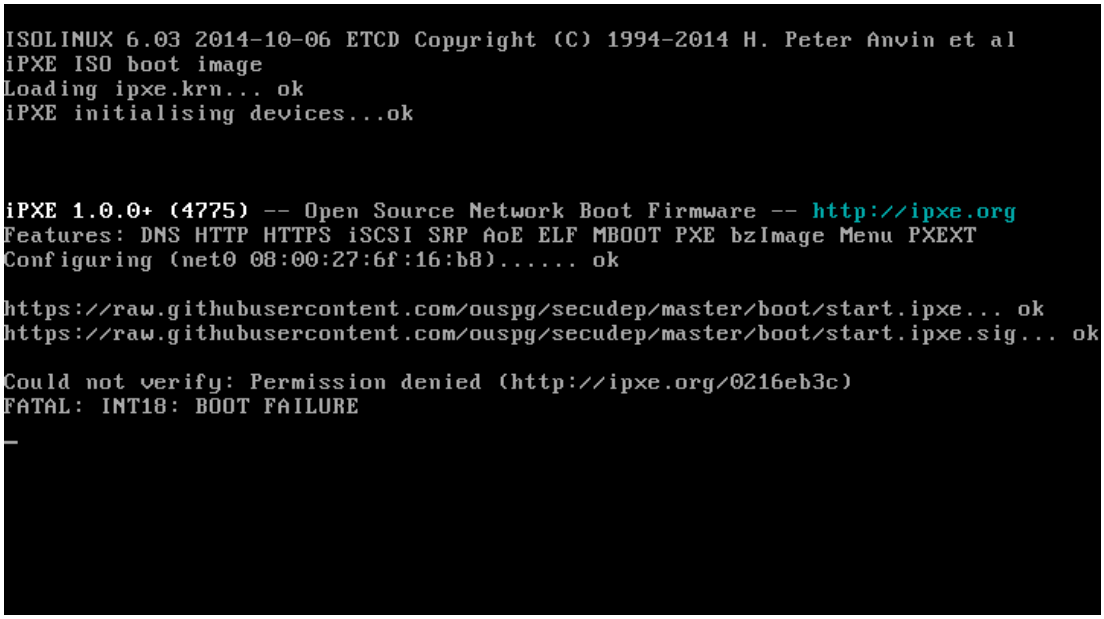

Figure 2. Installation process is halted when digital signature verification fails.

Kernel and initrd are the files needed to launch the Linux installation. Here traditional system uses TFTP protocol to serve these files, but over internet and secudep systems use HTTP protocl. Again TFTP and HTTP are susceptible to Man in the Middle attacks. TFTP is the de facto standard to deliver these files inside intranet systems. HTTP is used because the files are fetched from CentOS's official mirror over the internet. Secudep uses digital signatures to verify downloaded content.

After kernel and initrd are downloaded and digital signatures are verified the execution is handled to kernel. This means that secudep can't provide digital signatures to any following files. However, there's still two important steps in installation process: kickstart file and installation files.

Kickstart is CentOS specific file for automating unattended installation. The kickstart file is downloaded by the initrd system so secudep can't do digital signature verification. However, secudep uses HTTPS where traditional relies on NFS and over internet system uses HTTP. Both NFS and HTTP are suspecting to Man in the Middle attacks.

Installation files are downloaded and then installed into hard drive to achieve the operating system installation. Operating system installer is usually trusted to verify digital signatures (e.g. CentOS uses OpenPGP [22] ("GPG") signatures) the downloaded content before extracting the files into hard drive. The CentOS documentation [27] states that

> Each stable RPM package that is published by CentOS Project is signed with a GPG signature. By default, yum and the graphical update tools will verify these signatures and refuse to install any packages that are not signed, or have an incorrect signature. You should always verify the signature of a package prior to installation. These signatures ensure that the packages you install are what was produced by the CentOS Project and have not been altered by any mirror or website providing the packages.

However, when initrd file is downloaded over insecure protocol or file content is not verified against signature it's possible for malicious third party to inject it's own OpenPGP keys into initrd and point installation system to malicious host serving the operating system installation files and thus gain full control of the installed system.

4. DISCUSSION AND CONCLUSION

- FIXME: remove this list
- CONCLUSIONS: reference to purpose of study
- CONCLUSIONS: value of / reasons for the study
- CONCLUSIONS: review of important findings / conclusions
- CONCLUSIONS: comments, explanations or speculations about findings
- CONCLUSIONS: limitations of study
- CONCLUSIONS: implications of study or generalizations
- CONCLUSIONS: recommendations for future or practical applications - USUALLY SKIPPED

This thesis took a look what network based risks could face installation infrastructure and then studied what kind of means could be used to protect the initial phases (before operating system kernel took the control of execution) of installation process using encryption and digital signatures.

Protecting every step of communications over networks is important and protecting installation infrastructure is no exception. This thesis has shown that it's possible to take a step further in a more secure installation infrastructure by using two technologies: encryption and digital signatures.

More secure systems can be build step by step by combining simple individual components without the need for designing a whole new systems and technologies. Replacing old components (like TFTP, NFS and HTTP protocols) with new ones (HTTPS protocol) and increasing the use of digital signatures is a small steps to take for big benefits in security. Also when using HTTPS it's possible to use HTTP's authentication schemes to hide installation scripts (kickstart files, etc.) which otherwise would be visible to internet.

Linux distributions and other open source operating systems use OpenPGP or other digital signature methods to protect the installation packages from outside tampering which is a really good and important thing to do. Some Linux distributions also protect the package database meta data with digital signatures, but some distributions have that functionality turned off by default. Maybe mirrors at some point could take step forward and enable HTTPS so files like kernel and initrd, and package database meta data could be securely downloaded?

The public key to verify digital signatures is also embedded into initrd file. Is the initrd file downloaded and verified so that the embedded public key can be trusted by the installation process?

More testing and verification should be performed for the iPXE and it's TLS implementation and digital signature capabilities. This was intentionally left out from this thesis.

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