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SECURE DEPLOYMENT STORY FOR CHALLENGING ENVIRONMENTS

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ABSTRACT

Network based automatic installation of an operating system is and has been a crucial method to manage masses of computers. Protecting every step of the installation is important. Ability to trust the installation system to complete operating system installation safely and produce secure installation is important step in information security life cycle.

This thesis reviews past 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 study how the situation could be improved by using cryptography using Transport Layer Security (TLS) protocol and digital signatures. This thesis shows how these two existing technologies can be used to provide more secure installation system.

Proof of concept implementation using TLS and digital signatures is specified, developed and then compared to already existing and publicly available installation system.

Keywords: deployment, network protocol, operating system, installation system, network security

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Avainsanat: esimerkki, sanoja

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FOREWORD

I have been writing software, and designing, building, operating and tearing down Linux and UNIX systems for two decades. Installing operating system has been important part of life cycle of Linux and UNIX systems.

This thesis was motivated by the need for modernizing operating system installation over Internet. It's big subject with lots of little details to work on. This thesis is just small but important part of it.

I hope my work with this thesis can contribute back to everyone who has made my life so much easier with their installation systems.

I would like to thank my supervisor Prof. Juha Röning for the opportunity to do this thesis for Oulu University Secure Programming Group. Huge thanks to Christian Wieser for continuously taking the time to sit down with me for followup and pushing me forward.

Thanks to everyone who attended OUSPG Open 2016[1] and especially for everyone who participated the Thesis Review session, and read my work and gave feedback. Truly appreciated.

Thanks to my dad and sister for taking the time to read my work and giving valuable feedback. Hugs to my spouse Ella, who not only read and commented my work, but also endured the process of me writing it while also finishing her master's degree.

[1] https://github.com/ouspg/ouspg-open

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)
IPMI	Intelligent Platform Management Interface
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 (IETF)
RSA	Public-key cryptosystem named after Ron Rivest, Adi Shamir and Leonard Adleman
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 [1].

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, and require a human interaction as little 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 then 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) and then identifies what network based risks there are to installation system. The next chapter contains design principles of proof of concept installation system which tries to mitigate against the identified risks. Then the proof of concept implementation is compared against another installation system. Finally in conclusions and discussion chapter the findings are summarized and recommendations are given for new research and development, 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. Information Security

One definition of information security (InfoSec) is given in Finnish legislation, Government Decree on Information Security in Central Government (681/2010), which states that "information security means administrative, technical and other measures and arrangements to comply with secrecy obligations and restrictions on use related to information, as well as to ensure access to information and its integrity and availability" [2].

The Finnish national security audit criteria ("Information security audit tool for authorities" or "Katakri" for short) further divides information security into three separate divisions called security management, physical security and information assurance [3].

Katakri's security management is about how information security should be built-in into organization from management down to each individual person. Security management contains subjects like organization's security principles, security management tasks and responsibilities, risk management, continuity and personnel security.

Physical security as the name implies consists of protecting information from physical access. "The aim of physical safeguards is to deny surreptitious or forced entry by intruders, to deter, impede and detect unauthorised actions and allow for segregation of personnel in terms of access to Classified Information on the need-to-know basis" [3].

Katakri's Information assurance has information security requirements for electronic information.

1.1.1. Information assurance

Katakri's Information assurance requirements are divided into four separate sections: communications security, systems security, data security and operations security.

Communications security is about computer networks, devices connected to such networks and networks connected to other networks.

Systems security is about access controls, privileges and authorizations when using computers and computer networks. Further when using the systems, proper audit logging, protection against unwanted software, and incident detection and recovery are required.

Data security is about keeping the secrets secret when the data is either stored somewhere or moved from places to places.

Operations security contains day to day tasks for managing information processing environment life cycle, for example change management, backups and software vulnerability management. Operations security also contain requirements for handling and transfer of classified information.

1.1.2. This thesis in Information Security landscape

Security of installation system can be put under information assurance section of Katakri. Further, it can be categorized under operations security. In operations security, installation system's role is the very beginnings of information life cycle management. Secure installation system takes care of setting up appropriate and properly secured operating system installation to computer which then can be trusted.

Implementation of installation system need to take care of the requirements in communications, systems and data security to be able to achieve secure installation.

In this thesis it's assumed that proper management security and physical security are already in place.

1.2. Role of Humans

Information security is not only a technical issue. Since humans operate the computers, networks and software, information security is also a people problem [4][5]. Roughly the people problem can be divided into two categories: psychological attacks against human (social engineering) and "getting things done".

Social engineering is attack against human psychology and cognitive biases. Attacks like phishing or pretexting are used to exploit human weaknesses and good willingness to gather information like user names, passwords or credit card data. The person under social engineering attack might think she's not providing anything sensitive or harmful, but social engineering attacker could use bits and pieces of information from multiple attacks to gain whatever she's looking [6][5].

Another social engineering attack worth mentioning is tailgating or piggybacking [7]. In case of successful tailgating or piggybacking, the attacker gains physical access to premises which can then lead to for example stealing of information or assets like computers, physical keys, ID badges and money. Or the attacker might be planting hardware like physical key logger, listening device or USB (Universal Serial Bus) memory with malware.

Compared to social engineering attack against human is the "getting things done" where human is just trying to get through the day without any intention to do anything malicious. Employee has something which needs to be done, maybe under stress and pressure, and technical information security measures like pop up window alarming user about something or even window asking for user password, are distraction from the task at hand. Such pop ups are however so common that humans are constantly practiced to click "OK" to continue without even reading nor thinking about the reason or content of such notifications [5].

In case of installation system, the "getting things done" is the more probable information security issue. Imagine integration engineer with tight schedule working on customer's premises trying to get computer systems up and running. Any problem or obstacle increases stress and anxiety, and just "getting things done" without worrying about information security risks increases.

1.3. 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 [8]) and BOOTP ("Bootstrap Protocol", RFC951, published 1985 [9]) which could be used to allow "a diskless client machine to discover its own IP address" [9], TFTP ("Trivial File Transfer Protocol", RFC783, published 1981 [10]) "may be used to move files between machines on different networks implementing UDP." [10].

Later developments include RARP and BOOTP to be superseded by DHCP ("Dynamic Host Configuration Protocol", RFC1531, published 1993 [11]) and TFTP superseded by NFS ("Network File System", RFC1094, published 1989 [12]) which "provides transparent remote access to shared files across networks" [12]. PXE ("Preboot Execution Environment" [13]) 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" [14][15]).

1.4. Identifying Risks

CIA triad [16] divides network security into three elements: confidentiality, integrity and availability [5].

Confidentiality means that the sender of the message encodes the content so only a receiver can decode it and see the message. Confidentiality can be achieved using encryption. Encryption is a process of encoding a message using secret key so that decryption is only possible with the correct secret key. Keys used for encryption and

decryption might not be the same key. Confidentiality can be achieved in network for example by using TLS protocol [17] to encrypt network traffic.

Integrity control guarantees 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 [18][19] can provide non-repudiation. Standards such as S/MIME [20] or OpenPGP [21] 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 [17].

Availability means that the systems are up and operational. Perfect security could be achieved by turning everything off, but there's no usability in such systems. 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 such as facilities, computer systems and networks.

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.

All components in table 1 are susceptible to the issues with availability. For example, if the network or one or more components are not available, the whole stack of components is inoperative.

Component	Role	Risks
HTTP	File transfer	confidentiality, integrity
DNS	Name service	non-repudiation
NFS	File transfer	confidentiality, integrity
TFTP	File transfer	confidentiality, integrity
DHCP	Address resolution	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 [22][23].

DHCP is commonly used to assign an IP address to a client and give it various bits of information like TFTP server's IP address and DNS servers' IP addresses. Malicious DHCP server could take over the following 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 are used to transfer files between client and server. Malicious or compromised file server could be used to deliver malicious files to client which when executed in client 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, clients and servers 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 [24]. The backdoors could have been installed already on factory or firmware was infected with some malware previously ran on the machine. Mitigations for risks against hardware is out of scope of this work.

1.5. Current state

Software deployment technologies [25], securing virtual machines [26] as well as cloud computing security challenges [27][28] 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 operating system installation.

Alpine Linux's PXE Boot HOWTO [29] 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.

Alpine Linux's documentation was chosen as an example because of their claim that it's "for power users who appreciate security, simplicity and resource efficiency" [30]. Similar setup is required for other Linux distributions like Red Hat [31], and for Microsoft Windows [32].

As can be seen, 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 [17]) provides communications security using cryptography and authentication of one or both communicating parties.

DHCP is the standard protocol to centrally manage IP addresses for clients. It's difficult to replace so it's shortcomings need to be countered with other means.

Also DNS (Domain Name System, RFC1035 [33]) is a vital protocol to the internet. It provides translation from name to IP addresses and back (and other name services). DNS is also a standard protocol. Work to protect DNS traffic has been done (DNSSEC, RFC4035 [34]) and DNSSEC is slowly getting a foothold to protect DNS communications. The risk for DNS in installation systems is Man-in-the-Middle attack. Without

DNSSEC it's possible to continue using DNS and use other means outside of DNS protocol to verify DNS is working as it should.

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

1.6. Challenging environments

Computer networks are not safe nor secure [35]. Internet being the most unsafe of networks. It requires only one compromised device in a network to make the whole network unsafe. 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's path someone might be listening or even altering the connection to ones own agendas. It might be governmental body (like NSA's PRISM program [36]), 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 business intranets where both governmental 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 describes how his team infiltrates networks and moves there laterally to gain what they are after [37]. Therefore intranets should be treated with same level of mistrust as internet.

1.7. Mitigation

Risks can be mitigated by using trusted media, secure communication channels 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 Man-in-the-Middle 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 Man-in-the-Middle attack. If signature check fails the boot process should be halted.

1.8. Comparison to virtualization and cloud

Installing operating system to virtual machine (in a cloud or other virtualization platform) enjoys many benefits compared to installation to a physical hardware. Virtualization gives easier "programmable" access to every state of virtual machine installation from setting up the machine itself and it's parameters (like processors, memory

amount, disk space, network) to pre-building ready operating system images (machine images) to be booted in the cloud. This is called “Infrastructure as Code” or IaC [38].

Infrastructure as Code can be achieved for example with tools like Packer [39] which can be used to build machine images, and Terraform [40] to set up virtual machines and launch machine images to produce running virtual machines. Both tools use simple description language where operations can be specified and then ran using the tool itself.

When building machine images it’s possible to have operating system installation files on local disk so no network access is required. Also many operating systems provide means to download the installation files beforehand and verify their authenticity. Or in case of cloud, it’s possible that the user can use pre made machine images provided by the cloud provider.

Physical computer however require physical access to be able to plug in devices and cables, turn power on and to control the first stages of startup before operating system is running.

There are remote management solutions like Intelligent Platform Management Interface (IPMI) which make it possible to remotely control physical hardware. Intelligent Platform Management Interface (IPMI) is a specification of interfaces for monitoring and controlling physical computer hardware remotely via network. Using IPMI it’s possible to command computer to turn on or off, and to control BIOS settings [41]. However, using IPMI still requires the physical connections to be made and proper configuration of IPMI.

2. IMPLEMENTING SECUDEP

To see if it's possible to use HTTPS and digital signatures, a simple proof of concept implementation of installation system called *secudep* was implemented. Source code can be found from secudep's project site on GitHub [1].

Secudep's implementation has three main design principles: ease of use, ease of deployment 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 system, but designs can shift more towards personal or per application installation systems.

Installation system 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 system the concentration should be on selecting and enforcing safe defaults, and guide user to make safe choices.

The proof of concept implementation uses public-key cryptography to digitally sign files so that the authenticity of those files can be verified. It should also be encouraged to regenerate new key material when updating signature files. This renders old installation system unusable and forces updating of installation media (for example USB mass media).

One security design principle is, for example, to halt the installation process when a security measure detects an anomaly. Such anomaly could for example be an active Man-in-the-Middle attack. If user is given a choice to continue, she usually does so. Probably without understanding or investigating what caused the issue, thus rendering the security measure useless and allowing the attack.

This implementation borrows lots of ideas and lessons learned from boot.foo.sh [42] and from installation system used by Faculty of Information Technology and Electrical Engineering in University of Oulu.

2.1. Tools

Secudep uses iPXE [43] as a network boot firmware. iPXE is a PXE [13] implementation with additional features such as support for booting via HTTP [15] protocol. Support for HTTPS can also be compiled in.

Secudep's iPXE binary build is done inside container using Docker [44] software containerization platform to achieve repeatable builds with managed dependencies. Docker is tool to easily build operating system level virtualization [45] containers. Instead of virtualizing the hardware like Xen or KVM, containers use operating system's namespaces to separate containerized applications from each other. Docker is not mandatory for producing the build.

[1] https://github.com/ouspg/secudep

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 the installation system using secudep has the following steps. After the list, all the steps are explained further.

1. Generate digital signing keys
2. Collect HTTPS servers' X.509 certificates for public key pinning
3. Build iPXE bootable media
4. Write configuration file
5. Generate contents for deployment

Digital signing keys are generated when deploying the installation system. Private key is used to produce the signatures and public key is embedded into the installation image.

The installation system is deployed to known HTTPS server. Thus this server's X.509 certificate can be fetched and embedded into installation image. This is now the only X.509 certificate to be trusted and no other HTTPS server can be used.

When digital signing keys are generated and X.509 certificates are fetched, it's possible to build the bootable installation media. This installation media file is written for example to USB memory and can be used to launch the operating system installation in a computer.

Configuration file binds things together. It specifies the HTTPS server, where the keys and certificates are and what operating systems can be installed and where the required files can be found.

After all other steps are done, the files to be deployed on HTTPS server can be generated. This step fetches all required files, calculates digital signatures and various boot scripts, and builds directory structure which then should be mirrored on the HTTP server.

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. CASE STUDIES

Three case studies were performed. The case studies build an arch from studying how current state of the art installation system works towards testing the promise of secudep to making installation system a more secure system to achieve operating system installation.

The first case study looks into an already existing installation system to verify what protocols are used in the process. This is done to verify what is written in the introduction chapter about the current state of the art.

Next case study compares results from the first case study with the implementation details of secudep. The purpose is to compare how already existing installation system differs from secudep.

Third and last case study looks into secudep's promise to make installation system more secure. This is done by simulating the attack scenarios, for example Man-in-the-Middle attack, and observing how secudep behaves.

3.1. Case Study 1: Identify Protocols

3.1.1. What was studied

The purpose of this case study is to identify network protocols used in online installation system system. This study also verifies the involved protocols which were described in the introduction chapter.

For installation system a service called boot.foo.sh [42] is used. Boot.foo.sh was chosen because it's open service known to be used to automatic installations in enterprises and it has been an inspiration to this thesis to make installation system more safer to use.

Boot.foo.sh is used to install CentOS 7 Linux operating system. CentOS Linux is community driven effort to provide free alternative to Red Hat Enterprise Linux (RHEL). CentOS is built using RHEL source code. Red Hat has 67 % market share of Linux distribution market according to Gartner's analysis [46].

3.1.2. How it was done

The installation was done using virtual machine. VirtualBox was chosen as a virtualization software because it's free, open source and has easy to use network traffic recording functionality.

With VirtualBox's network traffic recording it's possible to get network traffic captured for the whole lifetime of virtual machine. The capture is saved as standard PCAP file which can later be opened in network protocol analyzer for investigation. Figure 1 has the typical traffic capturing setup with computer using the installation system, another computer recording the traffic, network switch to arrange traffic flows and the Internet containing the installation system in use.

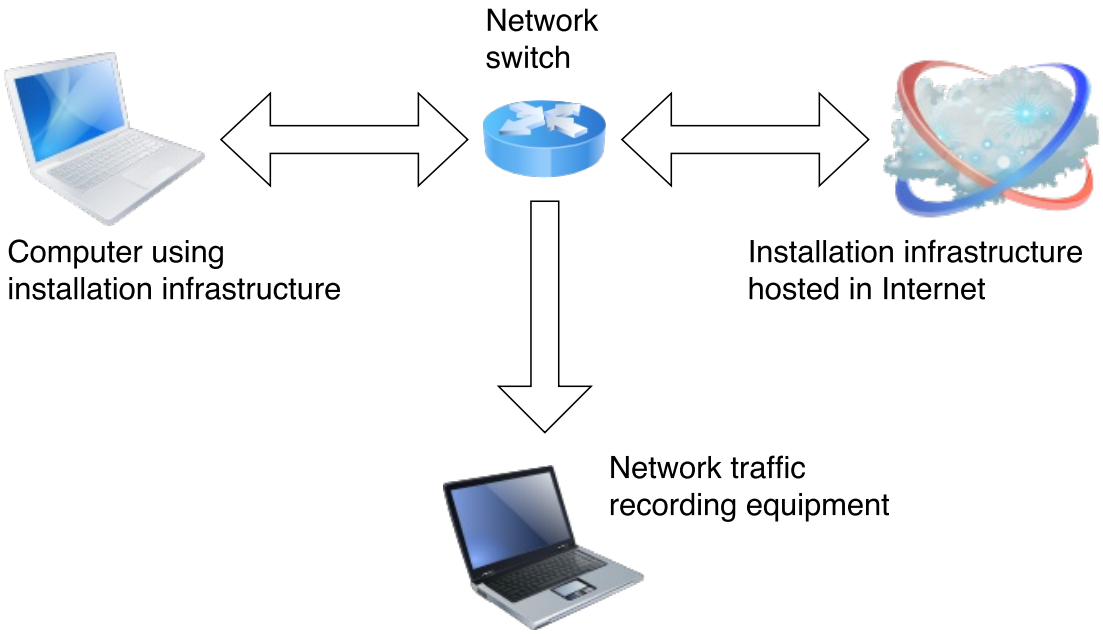

Figure 1. Network traffic recording setup.

Traffic capture was then analyzed using Wireshark network protocol analyzer. Wireshark is free and open source network protocol analyzer which has capability to help expert user analyze many different network protocols and their internals.

Traffic analysis was done by hand looking the captured traffic recording and identifying protocols used.

3.1.3. Results found

Traffic recording was 788 megabytes of network traffic containing over 883 thousand network packets. Recording contains time span of a bit over nine minutes.

Step	Protocol
Address resolution	DHCP
Name resolution	DNS
Boot menu	HTTPS
Kernel and initrd	HTTP
Kickstart	HTTP
Installation files	HTTP (DS)

Table 2. Table of found protocols and their role. DS in table means Digital Signatures.

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

Steps are identified and named for each system used to achieve the installation. The steps are discussed in chronological order of appearance as found from traffic recording.

3.1.4. Analysis of results

"Address resolution" is the first step and it's purpose is to get IP address and DNS server addresses for system to be installed. DHCP is the standard protocol for this, and was also found to be used here.

"Name resolution" is used to translate host names into IP address to communicate with other servers. DNS protocol is used for name resolution needs.

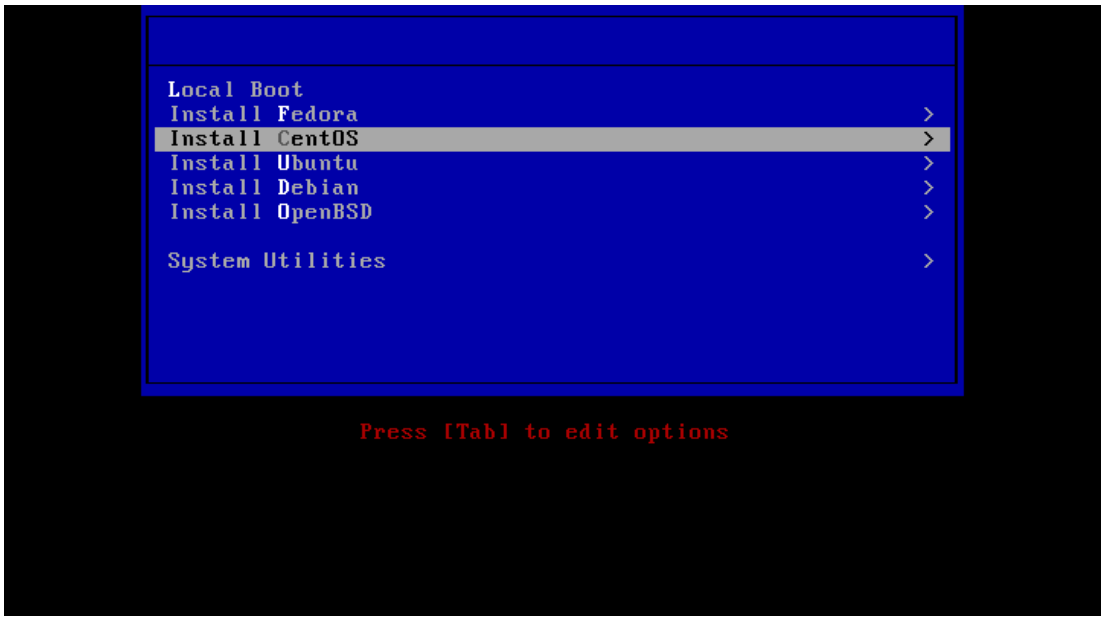

Figure 2. boot.foo.sh boot menu showing selection of operating systems.

"Boot menu" is used to display choices of operating systems to be installed. Boot menu from boot.foo.sh can be seen in figure 2. Boot.foo.sh uses HTTP protocol to fetch various files needed to display the boot menu.

"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. HTTP was used to communicate with CentOS 7 mirror to fetch the needed files.

"Kickstart" is CentOS specific file for automating unattended installation. It's set of instructions downloaded and executed by the installation process. Kickstart file is downloaded by software inside initrd system so at this point the control of installation is already switched to CentOS' installer. HTTP was used to communicate with boot.foo.sh server to fetch the kickstart file.

"Installation files" are the contents of operating system to be installed. The files are downloaded and extracted to hard drive to achieve the installation. Operating system installer is usually trusted to verify digital signatures (e.g. CentOS uses OpenPGP [21]

("GPG") signatures) the downloaded content before extracting the files into hard drive. The CentOS documentation [47] 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 web site 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.

3.2. Case Study 2: Comparing boot.foo.sh and secudep

3.2.1. What was studied

This case study compares implementation details of secudep to already existing installation system solution which was studied in case study 1. The purpose of this is to see the differences between used network protocols between these two systems.

3.2.2. How it was done

The results from case study 1 was used as a base and then implementation details about secudep were compared against the base.

3.2.3. Results found

Step	boot.foo.sh	secudep
Address resolution	DHCP	DHCP
Name resolution	DNS	DNS
Boot menu	HTTP	HTTPS (DS)
Digital signatures	N/A	HTTPS
Kernel and initrd	HTTP	HTTP (DS)
Kickstart	HTTP	HTTPS
Installation files	HTTP (DS)	HTTP (DS)

Table 3. Comparison between how boot.foo.sh and secudep use of protocols. DS in table means Digital Signatures.

Results of comparing boot.foo.sh and secudep can be found from Table 3. Boot.foo.sh results are same as in case study 1. The differences between boot.foo.sh and secudep are discussed next.

3.2.4. Analysis of results

Address and name resolution are identical in both systems. As discussed in introduction chapter these protocols are standards and difficult to change.

”Boot menu” is used to display choices of operating systems to be installed. HTTP is used in boot.foo.sh and is susceptible to Man-in-the-Middle attack. Secudep uses HTTPS (HTTP over TLS) with signed files to remediate this issue.

Secudep uses digital signatures and the signature files are fetched over HTTPS. This is a step missing from boot.foo.sh.

Kernel and initrd are the files needed to launch the Linux installation. Both boot.foo.sh and secudep systems use HTTP protocol. Again HTTP is susceptible to Man-in-the-Middle attacks. 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.

3.3. Case Study 3: Testing attacks against secudep

3.3.1. What was studied

This case study consist of simulated attacks against implementation of secudep. Secudep's main defense against attacks is the use of encryption (TLS) and digital signatures.

Table 3 on page 20 contains list of protocols involved in operating system installation process.

The first two protocols, DHCP for address resolution and DNS for name resolution are insecure and susceptible for example to Man-in-the-Middle attacks. Loading the boot menu over HTTPS with digital signature check should validate that DHCP and DNS are not tampered with and installation can proceed further.

After boot menu step is done, secudep loads kernel and initrd over unsecured HTTP connection. For example Man-in-the-Middle attack could change kernel or initrd to another files, but digital signature verification should notice that.

3.3.2. How it was done

Secudep boot media contains at least two public keys. One is for digital signature verification, and one or more are for verifying HTTPS connections. More public keys are loaded over HTTPS connection while boot progresses.

Testing that these verifications works can be done by either omitting the public key from Secudep boot media or serving wrong public key from Secudep's HTTPS server.

Attack against	Protocol	Defense
Address resolution	DHCP	Verification done in boot menu
Name resolution	DNS	Verification done in boot menu
Boot menu	HTTPS (DS)	Certificate and digital signature verification
Digital signatures	HTTPS	Certificate verification
Kernel and initrd	HTTP (DS)	Digital signature verification
Kickstart	HTTPS	Certificate verification
Installation files	HTTP (DS)	Operating system takes control

Table 4. Attack and it's defense in various steps of installation. DS in table means Digital Signatures.

Table 4 lists steps in boot process and what verification is used in each step.

DHCP and DNS Man-in-the-Middle attacks can be detected when X.509 certificate verification fails and HTTP Man-in-the-Middle attacks can be detected when code signing verification fails.

File	Used for	Where it's located
DS certificate	Verify digital signatures	in bootable media
X.509 for HTTPS	Verify HTTPS connection(s)	in bootable media
Boot menu DS	Verify boot menu is not changed	File on HTTPS server
Kernel DS	Verify kernel is not changed	File on HTTPS server
Initrd DS	Verify initrd is not changed	File on HTTPS server

Table 5. Different files used for verification in various steps, where they are used and where they are located. DS in table means Digital Signatures.

Table 5 lists all files used for various steps in process. Any failure in verification should halt the installation process.

3.3.3. Results found

Five different tests were made and results can be found from table 6. Every simulated attack was noticed and the installation was halted. Table also gives iPXE's error code for each tested case.

3.3.4. Analysis of results

Five different tests were made by breaking one verification step at a time and trying to run the installation. The result was observed and material collected.

File	Halts installation	iPXE error code
DS certificate	True	0216eb3c
X.509 for HTTPS	True	0216eb3c
Boot menu DS	True	0227e13c
Kernel DS	True	0227e13c
Initrd DS	True	0227e13c

Table 6. Results of testing secudep's implementation by simulated attacks.

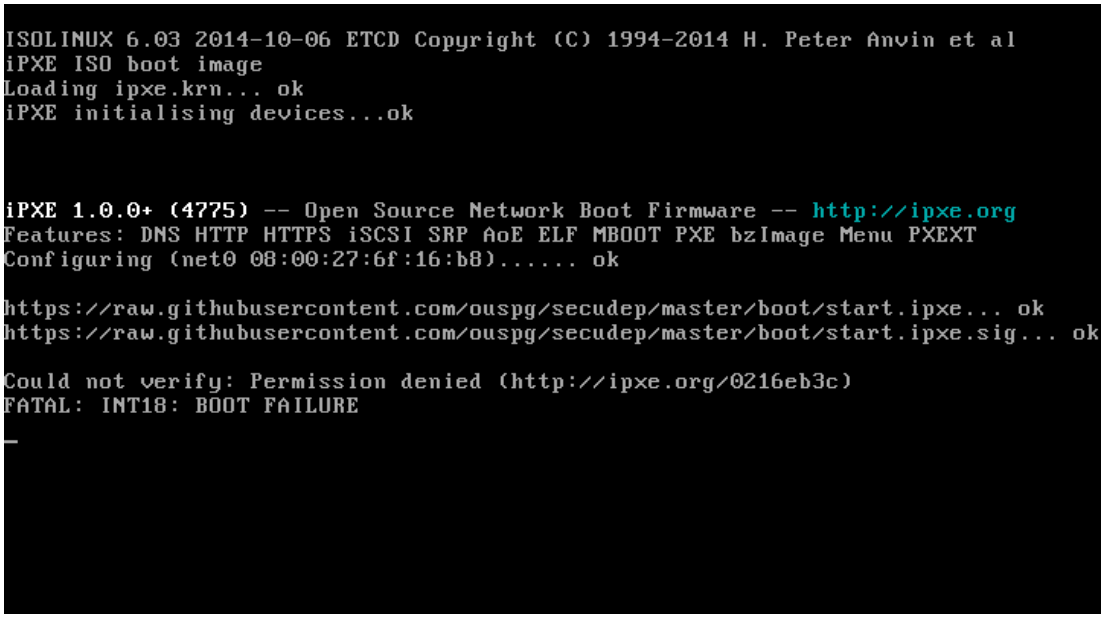

Figure 3. Installation process is halted when digital signature verification fails.

Two distinct iPXE error codes were found while conducting the tests. One example of such error is shown in figure 3. In the figure the installation process couldn't verify digital signature, and the process was halted and it can't proceed further.

The first error code, "0216eb3c" is documented[1] in iPXE web page as "Error: No usable certificates". This matches what was tested. In the test a wrong certificate was provided so the error given is correct.

The second error code "0227e13c" is documented[2] in iPXE web page as "Error: RSA signature incorrect" with additional notes stating

> This error indicates that an RSA signature was found to be incorrect.
>
> Things to try:
>
> 1. Check that all certificates are correct.
> 2. If you are verifying a digital signature using the imgverify command, check that you are using the correct signature file.

[1] http://ipxe.org/err/0216eb3c
[2] http://ipxe.org/err/0227e13c

This matches what was tested. Either wrong RSA signature was given in test or the file was changed so that the RSA signature verification should fail.

This case study tested only the most obvious security issues. More sophisticated attacks might exploit the implementation weaknesses in iPXE and other software and hardware. Thus this case study is not proof of perfect security, but shows that at least some cases of attacks can be detected and reacted on.

4. DISCUSSION AND CONCLUSION

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

Protecting every step of communications over networks is important and protecting installation system is no exception. This thesis has shown that it's possible to take a step further in a more secure installation system 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 already existing ones (HTTPS protocol) and increasing the use of digital signatures are small steps to take for big benefits in security. Also when using HTTPS it's possible to use different 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 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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