Distributed Systems

Security

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24.06.2024

Definition

What is (information) security?

Introduction

Information Security[1]

"Information security [. . .] is the practice of protecting information by mitigating information risks. [...] It typically involves preventing or reducing the probability of unauthorized/inappropriate access to data, or the unlawful use, disclosure, disruption, deletion, corruption, modification, inspection, recording, or devaluation of information. It also involves actions intended to reduce the adverse impacts of such incidents. Protected information may take any form, e.g. electronic or physical, tangible (e.g. paperwork) or intangible (e.g. knowledge). Information security's primary focus is the balanced protection of the confidentiality, integrity, and availability of data (also known as the CIA triad) while maintaining a focus on efficient policy implementation, all without hampering organization productivity.".

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- Separation between policy and methods
  - Security policies (Set of rules)
  - Security methods (Mechanisms for enforcement)

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Secure Systems

Secure Systems

- . . . do not exist.

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- The completely secure firewall:

http://www.brauwesen-historisch.de/seitenschneider.jpeg

"It is easy to run a secure computer system. You merely have to disconnect all dial-up connections and permit only direct-wired terminals, put the machine and its terminals in a shielded room, and post a guard at the door."

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- An application can be considered secure, if the cost for an attacker are higher than the value of the protected value

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  - Privacy:
    Personal attributes must be kept confidential and the anonymity should be preserved if possible

Terms

What is the difference between authentication and authorization?

Terms

- Authentication:
  - Verification of an identity
  - Mutual authentication of communication peers is required, e.g., user ↔ computer
- Authorisation:
  - Have and exercise permissions
  - Security models
    - Discretionary Access Control
      Access matrix as abstract model
      Method: Capabilities, Access Control Lists (ACLs)
    - Mandatory Access Control

Threats

Which security goal can be threatened by what?

Threats

- STRIDE Model
  - **S** poofing ⇝ Authenticity
  - **T** ampering ⇝ Integrity
  - **R** epudiation ⇝ Non-repudiability
  - **I** nformation disclosure ⇝ Confidentiality
  - **D** enial of Service ⇝ Availability
  - **E** levation of Privilege ⇝ Authorization

Threat Examples

- Faulty specification of security policies

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- Eavesdropping

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- Theft of keys or masquerading (faking an identity)
- Active modification, deletion, or replay of messages
- Injection or infiltration of messages, emails, viruses, worms, Trojan horses . . .

Risk Assessment

https://iso25000.com/images/figures/en/iso25010.png

- May conflict with other characteristics of software quality
- Effort-benefit must be weighed
- Per threat:
  - Potential damage (life and limb, property damage, reputation)
  - Probability of occurrence
  - Probability of detection of occurrence
- The higher the risk, the more important the consideration as part of the security policy

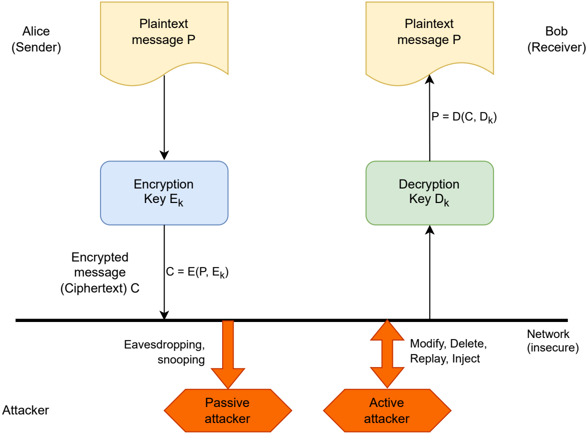
Agenda

- Cryptographic Concepts
  - Encryption Methods
  - Cryptographic Hash Functions
- Cryptographic Methods
  - Authentication
  - Digital Signatures
  - Key Management
- Layered Security
- Firewalls

Agenda

Cryptography

- Practise of techniques for secure communication
- Base model:

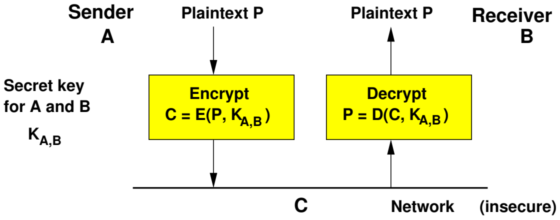


> Cryptographic methods are based on mathematical theory, but can be applied without in-depth understanding of the mathematical foundations.

Agenda

Symmetrical Encryption

- A secret key for encryption and decryption



Symmetrical Encryption

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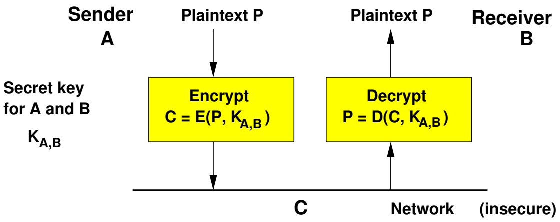

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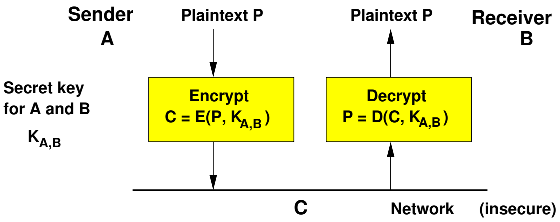
  - Low computational cost (fast)



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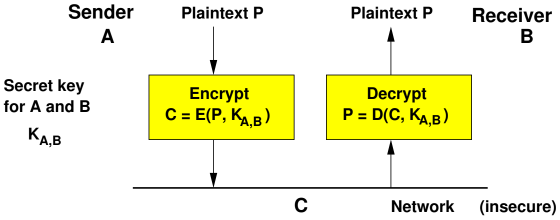
- Problems:
  - Key Management
  - Repudiable



Symmetrical Encryption

- Block algorithms
  - Encryption of data of fixed length, e.g., 64 bit
  - Alternatives:
    - Electronic Code Book
      - all blocks are encrypted independently from each other
    - Cipher Block Chaining
      - Encryption is chained with the previous encrypted block via an *XOR* operation
- Stream Algorithms
  - Bit or byte stream oriented
  - typically very fast, but missing standardization
- Examples:
  - DES Data Encryption Standard (US) historically most widespread representative
  - Triple-DES, IDEA, AES
  - RC4 (Stream Algorithm)

Asymmetric Encryption (public key encryption)

- A pair of keys is required (private and public key)
  - different keys for encryption and decryption → Hence the name *asymmetric*
  - **Assumption:** the secret can not be derived from the public key or the method with realistic computational costs

Asymmetric Encryption (public key encryption)

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  - **Assumption:** the secret can not be derived from the public key or the method with realistic computational costs
- Advantages:
  - No secrete channel for key distribution required → the secret key gets never transmitted
  - Public keys can easily be distributed using directory services
  - Non-repudiation is possible

Asymmetric Encryption (public key encryption)

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- Advantages:
  - No secrete channel for key distribution required → the secret key gets never transmitted
  - Public keys can easily be distributed using directory services
  - Non-repudiation is possible
- Drawbacks:
  - rather long keys are required (→ currently at least 2048 bit are recommended)
  - high computational cost
  - Reliable key management is required

Examples Asymmetric Encryption

Representatives

- RSA Algorithm
  - Rivest, Shamir, Adelman: 1978
  - based on prime factorization of big numbers → computational hard one-way problem
- Diffie-Hellman
  - Establishing secure connections from an unsecure state (without authentication)
- Elliptic Curve Cryptography (ECC)
  - based on rather modern mathematical methods
  - allows smaller keys with equivalent security
  - especially suited for resource constrained devices

Typical Use Cases

- Asymmetric Encryption
  - Authentication
  - Digital signatures
  - Key management
- Symmetrical Encryption
  - fast encryption of a bigger amount of data

⇒ Asymmetric methods are used to negotiate keys for subsequent symmetrical encryption (Session Key)

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- Layered Security
- Firewalls

Cryptographic Hash Functions

- Calculating a digital fingerprint for documents or messages → message digest
- Basis for digital signatures
- Hash function H
  - $h = H(P)$
  - *Message* P of arbitrary length
  - h Sequence of bits of fixed length (e.g., 128 bit)
  - cf. CRC
- Assumptions
  - Calculation of H is easy
  - The reverse operation, i.e., determining the original message for a given hash value is computational hard (→ one-way function)
  - Any change to the message P results in a different hash value (h)
- Examples:
  - MD5 (not considered secure anymore)
  - SHA-0, SHA-1, SHA-2, SHA-3

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Authentication

Authenticity and Integrity

Authentication and message integrity are not separable from each other

- What use is authenticity if the message can be changed?
- What use is message integrity if its sent by anyone else?

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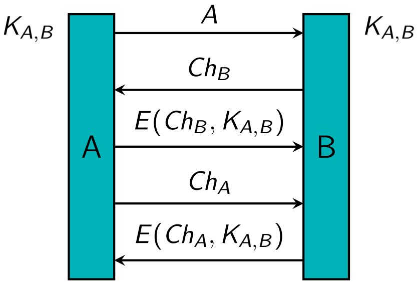
Procedure

1. First, setup of a secure channel with mutual authentication
2. Next, use a secret session key to ensure integrity (and confidentiality)

Authentication with Secret Keys

- Principle of a Challenge-Response-Protocol



$K_{A,B}$: common secret key

- Communication request A, contains the identity of A

- Problem: Management of many secret keys

→ Key Distribution Center (KDC) may be used

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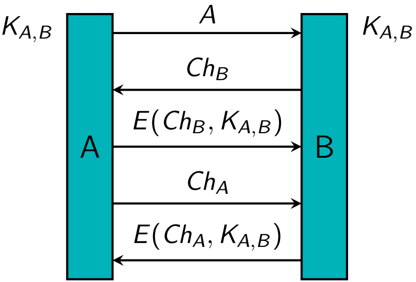

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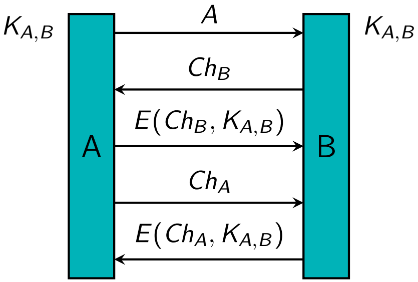


$K_{A,B}$: common secret key

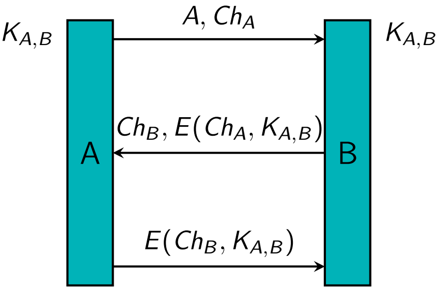
- Communication request A, contains the identity of A
- Challenge Ch_B (e.g., random number) posed by B
- B can check if the response contains Ch_B ($\rightarrow$ only A can be the communication partner)
  - analog in the reverse direction ($\rightarrow$ only B can be the communication partner)

- Problem: Management of many secret keys

$\rightarrow$ Key Distribution Center (KDC) may be used

On the Design of Secure Protocols (1/2)

- The design of a secure protocol is error-prone!
- Example: Seemingly simplified challenge-response-protocol

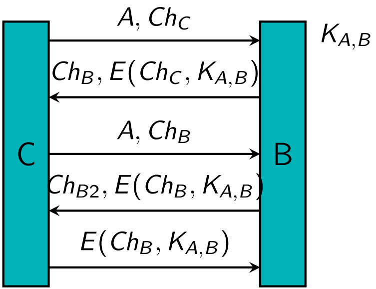


- Idea: Merging messages
  1. Communication request A **and** Ch_A
  2. Response to Ch_A **and** Ch_B
  3. Response to Ch_B
- Only three steps → more efficient?

- Claim: This protocol is **not** secure any more!

On the Design of Secure Protocols (2/2)

- Reflection attack: Attacker C, *not* knowing the secret $K_{A,B}$

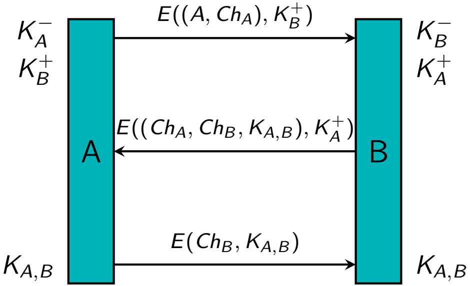


- C starts a first session and retrieves Ch_B
- C starts a second session using Ch_B as alleged own challenge
- C retrieves Ch_B encrypted with $K_{A,B}$: $E(Ch_B, K_{A,B})$
- C uses this to continue the first session

Result: B trusts C, even though C does not know the common secret $K_{A,B}$

Authentication with Public Keys

- Principle
  - No KDC required
  - Attribution of the public keys to the real persons must be ensured



- K_A^- secret key of A
- K_A^+ public key of A
- $K_{A,B}$ session key, generated by B, short-lived

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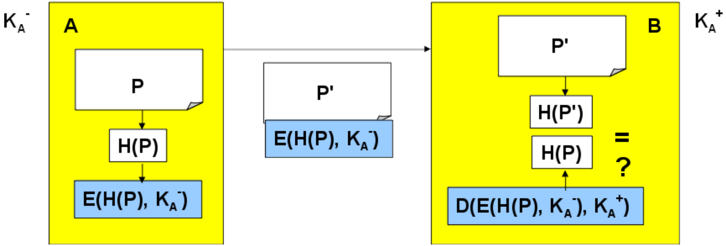
Digital Signatures

- Comparable to a physical signature
  - Must not be detachable from the signed document
  - Not (easily) forgeable
- Signature provides reliable determination of ...
  - Authorship
  - Non repudiation
  - Integrity
  - Authenticity
- ... but does not protect the confidentiality of the message

  → Requires encryption
- Combination of ...
  - Hash Algorithm
  - Public Key Infrastructure

Procedure

- Sign the message by encrypting the hash value of a message with the private key
- The public key can be used by the receiver to verify the validity of the signature



Procedure

1. Alice (A) is the sender and Bob (B) the receiver of a message
2. Alice uses the hash algorithm H on the plaintext message P to create a hash value $V_A = H(P)$
3. Alice encrypts the hash value V_A with her private key K_A^-

$$VC_A = E(V_A, K_A^-) \text{ (=Signature)}$$

4. The encrypted hash value is appended on the (unencrypted) message and transmitted along with the message
5. Bob decrypts VC_A using Alice's public key K_A^+

$$V = D(VC_A, K_A^+)$$

6. Determination of the hash value of message P:

$$V_B = H(P)$$

7. $V = V_B$?
   if yes: Signature is authentic and the message has not been modified

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Key Management

- Goal
  - Secure and efficient life cycle management for keys
    - Generation/setup
    - Distribution
    - Revocation
  - Trust in key management is mandatory!
- Different approaches
  - When working with secret keys:
    Key Distribution Center (KDC)
  - When working with public keys:
    Public Key Infrastructure (PKI)

  → Anything but trivial!

PKI Systems

- Main problem:
  - Secure distribution of public keys
  - Man-in-the-Middle (MitM) attack during key exchange is possible
- Basis
  - Certificates
    - Authenticity of public keys
  - Directory services
    - Lookup for public keys
    - e.g., LDAP (Lightweight Directory Access Protocol)

Certificates

- Certificates
  - Are used to confirm the authenticity of a public key
  - ⇒ Confirm the affiliation to a certain entity (person, service, organization . . .)
- Certification Authority (CA)
  - Issuing authority
  - Ensures the ownership of an key
  - Trustworthiness is required or the public of the CA must be certified itself by a higher CA
  - Controlled by central entity (root CA) which certifies the public keys of CA (→ chain of trust)
- Certification Revocation List (CRL)
  - Contains serial numbers of certificates which became invalid (have been revoked)

X.509 Standard for Certificates

- Versions: v1-v3
- Essential information of a certificate:
    - Version
    - Public key of the certificate owner
    - Distinguished Name (of the owner)
        - Common Name, CN
        - Organization, O
        - Organizational Unit, OU
        - Locality, L
        - State, ST
        - Country, C
    - Name and country of the issuing CA (Distinguished Name)
    - Validity period
    - Used algorithms
    - Extensions

Agenda

Which layer in the
OSI reference model
is responsible for security?

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None of them

Which layer in the OSI reference model is responsible for security?

~~None of them~~ All of them

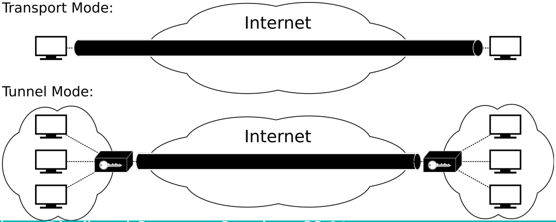
Link Layer Security

- IEEE 802.1X
  - Provides authentication and authorization
  - Requires a RADIUS[2] server
- IEEE 802.1AE (MACSec)
  - Provides confidentiality and integrity
  - Frame format is similar to Ethernet frame format
- Wireless link layer specifications like IEEE 802.11, IEEE 802.15.4, or Bluetooth directly address security concerns
  - For example WEP or WPA for WLANs

[2] RADIUS = Remote Authentication Dial-In User Service

Network Layer Security

- IPsec (Internet Protocol Security)
  - Originally developed for IPv6 but widely adopted for IPv4
  - Specified in RFC 2401 and 4301
  - Often used for VPNs (Virtual Private Networks)
  - Support two modes
    - Transport mode
    - Tunnel mode
  - Authentication Header (AH) protects integrity and authenticity
  - Encapsulating Security Payload (ESP) protects integrity, authenticity, and confidentiality



Transport Layer Security (TLS)

- earlier: Secure Socket Layer (SSL)
  - SSL 3.1 = TLS 1.0
  - TLS 1.3: RFC 8446 (2018)
- Security on the transport layer
  - The TLS protocol acts as a sublayer between the transport layer and the application layer
  - Transparent for all application layer protocols, e.g., HTTP, SMTP, IMAP ...
- Origins
  - Developed at *Netscape Communications* for their browser during the 1990s
- Concept
  - Authentication and encryption
  - Basis:
    - X.509 public key certificates
    - Symmetrical encryption with secret session keys

TLS Subprotocols

- Handshake protocol:
  - Server authentication
    - Server replies to client request with a certificate and preferences regarding the encryption method (RC4, IDEA, DES, 3DES, . . .)
    - Client generates master key, encrypts it using the public key of the server (as found in the certificate), and sends the encrypted master key and the selected method to the server
    - Server determines master key and authenticates itself with a message that has been encrypted with the master key
    - Subsequently keys derived from the master key are used
  - Optional client authentication
    - Server sends a challenge request to the client
    - Client responds with a signed request and client certificate
- Change Cipher Spec Protocol
- Alert Protocol: Error handling
- Application Data Protocol
- Record Protocol: Encoding and transfer (lowesest layer directly on top of TCP, symmetrical encryption using DES, TripleDES, AES . . .)

Popular implementations: OpenSSL, GnuTLS, LibreSSL, WoflSSL . . .

TLS Examples

- TLS requires a reliable transport layer service (→ TCP)
- For communication over UDP the Datagram Transport Layer Security (DTLS) is available
  - High relevance for IoT applications
- Examples
  - HTTPS
    - HTTP over TLS, https:// ...
    - Supported by all major web browses
    - Establishes a TLS connection
    - HTTP uses this connection for the secure transmission of confidential data
    - Port 443 is used instead of port 80
  - SMTPS
  - IMAPS, POP3S

Application Layer Security

- Protecting application data via cryptographic methods against attackers
- E.g., by encrypting or signing of content data
- Examples:
  - S/MIME and GPG/PGP for confidential (encrypted) and authentic (signed) emails
  - .htaccess for access control on web pages ($\rightarrow$ only reasonable in the combination with TLS)
  - DNSSEC and DANE as extensions for DNS
  - OSCORE (Object Security for Constrained RESTful Environments)

Conclusion

- Wouldn't it suffice to employ security measures on one level?

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→ If the content is encrypted, it cannot be accessed by any unauthorized user on any layer

- BUT metadata is still unencrypted → e.g., information who communicates with whom is still accessible for everyone
- An attack on the link layer or network layer may redirect the traffic

⇒ Security measures on all layers may make sense depending on the protection goals

Agenda

What is a firewall?

Firewalls

- Goals
  - **Monitoring** of all incoming (and outgoing) **traffic**
  - **Prevent intruders**
  - Allow for **authorized access** only
  - Keep the performance loss as low as possible

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- Assumption
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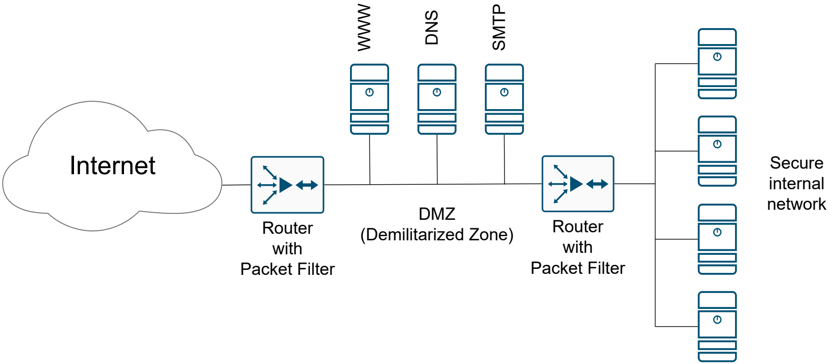
- Classification:
  - according to the layer where the checks are performed:
    - Network layer based filters (packet filter, screening)
    - Application level gateways
    - often combined

Packet Filter

- Analysis per packet
- Typically employed in routers
- Rules for blocking
  - Blocking subnets
  - Blocking hosts
  - Blocking services
  - based on IP addresses and port numbers
- Advantage
  - low overhead $\Rightarrow$ high performance
- Drawback
  - complex, non-modular rules for bigger networks
  - Logging is difficult
- Example: iptables, nftables

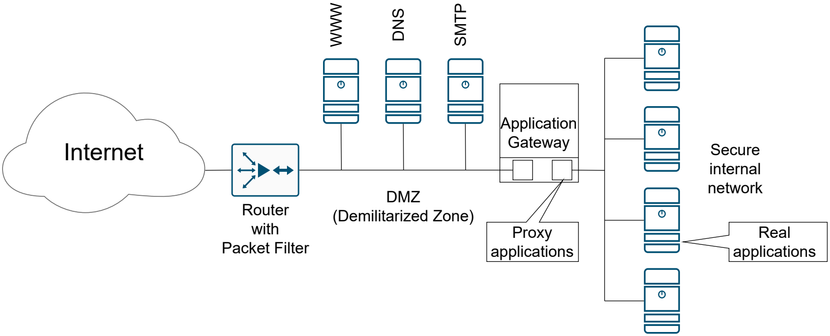
Packet Filter – Architectural View



Application Level Gateway

- Collection of specialized proxy application as replacement for the usual applications
- Common for HTTP, SMTP, X protocol, ...
- Proxy applications typical include
  - Access monitoring
  - Logging
- Advantage
  - high degree of security
- Drawbacks
  - Require proxies
  - New applications require adaptations
  - High performance overhead

Application Level Gateway – Architectural View



You should now be able to answer the following questions:

- When do you consider a system secure?
- Which protection goals do exist?
- What is the difference between symmetrical and asymmetric encryption?
- How does the Challenge-Response-Protocol work?
- How does authentication with public keys work?
- How does a digital signature work?
- What is a PKI and what is a certificate?
- Which security measures can be taken at which level?
- What is a firewall?