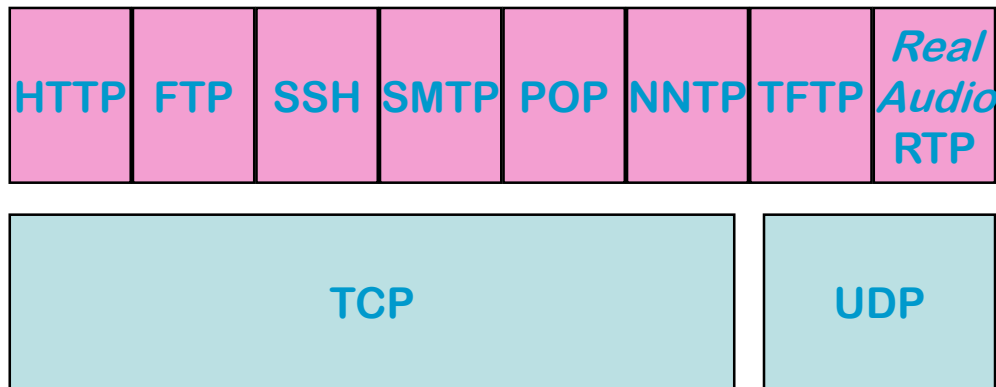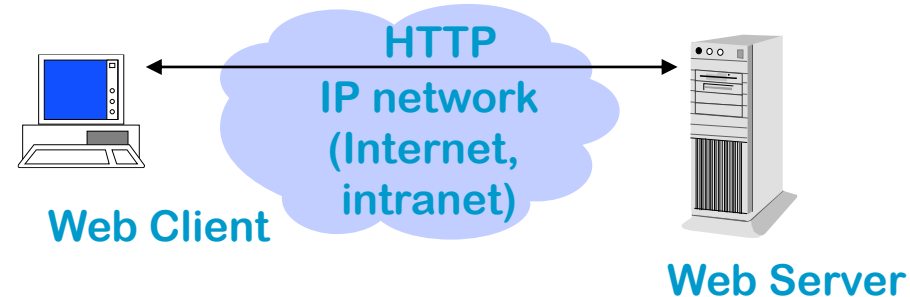# Application Layer

About This Module

■ The application layer of TCP/IP consists of the distributed applications themselves – it is the topic of the courses on information systems and distributed systems

■ In this module, we focus on the relationship between the application layer and the lower layers.

■ We review

1. Examples of application layers
2. The "End-to-end Principle" and Application Layer Gateways

1. Examples of Application Layer: DNS; Web; Email

■ Application **programs** (ex. netscape) use a set of well defined application layer **protocols** (ex. HTTP) and **formats** (ex: HTML)

■ A given Application Layer protocol uses TCP or UDP

HTTP	FTP	SSH	SMTP	POP	NNTP	TFTP	*Real Audio* RTP

TCP	UDP

■ Application layer runs on hosts

▶ does not involve routers

HTTP

IP network (Internet, intranet)

Web Client

Web Server

3

Example: Email

- email address: identifier human user
  - format: `user@domainName`
  - `domainName` is a name according to DNS

1

UA	MTA

mkksun34.
mycorp.com

email to: al@di.epfl.ch

2

MTA

sicmail.
epfl.ch

3

lrcsuns.
epfl.ch

5

MTA	UA

4 in
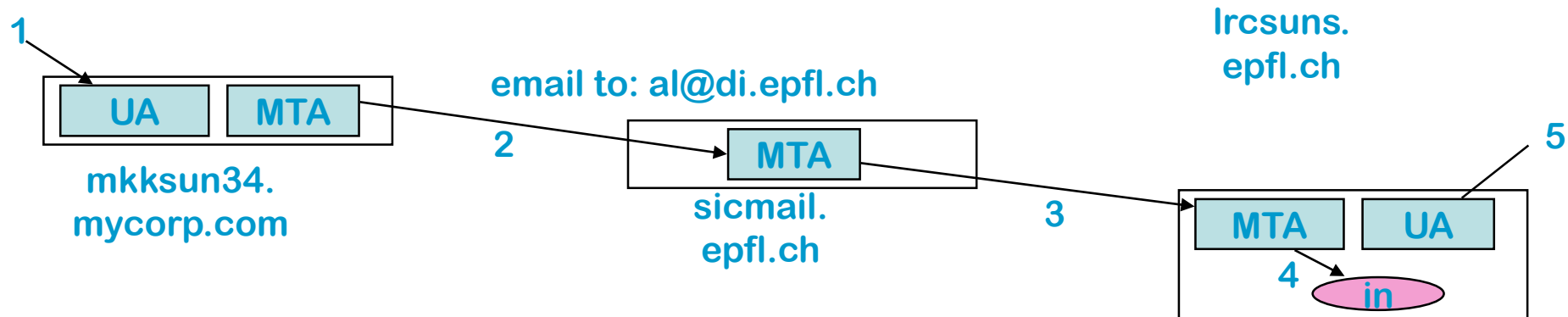
1. user creates mail with UA; UA triggers MTA to send it
2. MTA sends to destination or mail exchanger, using SMTP (simple mail transport protocol). SMTP uses TCP
3. mail exchanger sends to destination MTA using SMTP
4. destination MTA delivers to user mailbox
5. user reads mailbox with UA

4

SMTP Session Example

■ use `telnet <destMachine> <serverPort>` to communicate manually with a server

■ example

```
lrcsuns:/export/home1/leboudec$ telnet localhost 25
Trying 127.0.0.1 ...
Connected to localhost.
Escape character is '^]'.
220-lrcsuns.epfl.ch Sendmail/LRC ready at Mon, 23 Jun 1997 16:47:26 +0200
220 ESMTP spoken here
HELO lrcmac45.epfl.ch
250 lrcsuns.epfl.ch Hello localhost [127.0.0.1], pleased to meet you
MAIL FROM: leConcombreMasque
250 leConcombreMasque... Sender ok
RCPT TO: leboudec@di.epfl.ch
250 leboudec@di.epfl.ch... Recipient ok
DATA
354 Enter mail, end with "." on a line by itself
ceci est un essaiiiii
.
250 QAA15185 Message accepted for delivery
QUIT
221 lrcsuns.epfl.ch closing connection
Connection closed by foreign host.
```
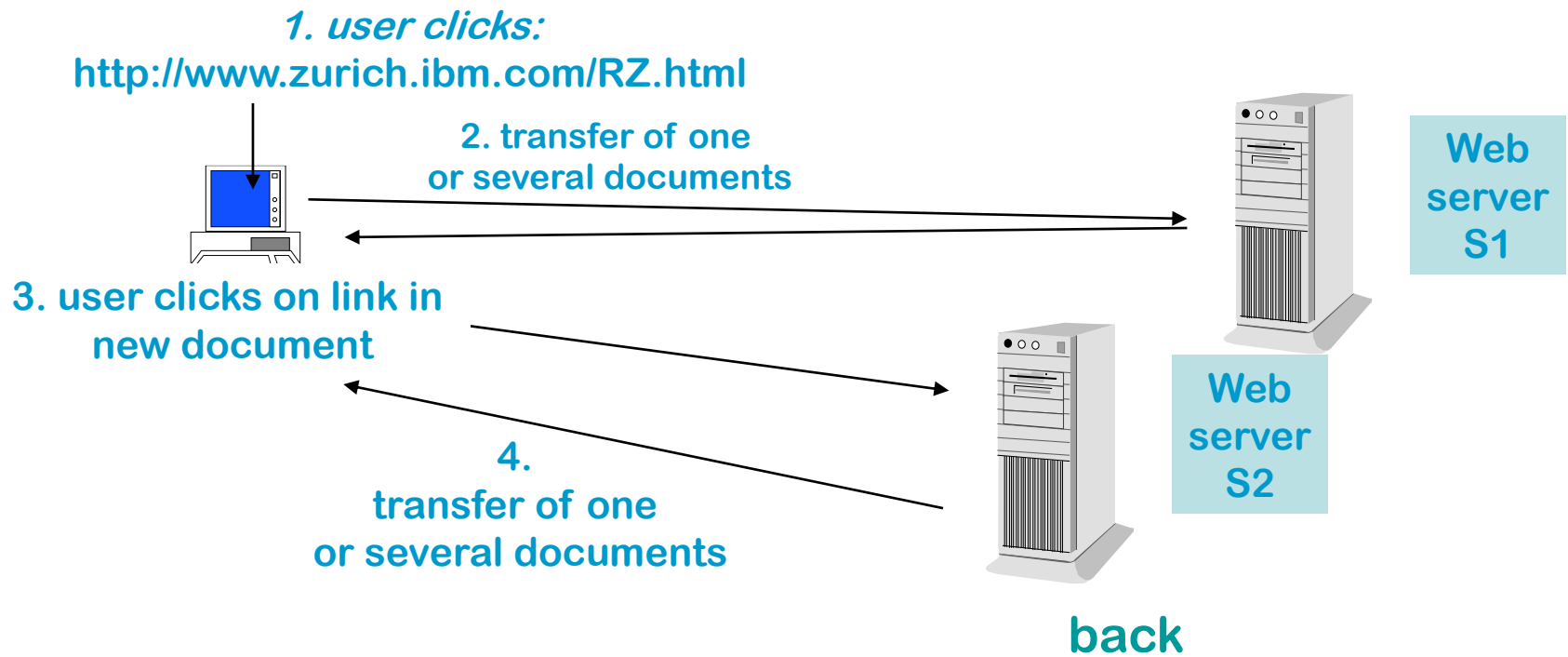
Example: World Wide Web (WWW)

- three components
  - file transfer protocol: HTTP (hyper text transfer protocol); uses TCP
  - format for documents with links ("hyperdocuments"): HTML (hyper text markup language)
  - URLs (universal resource locators)

1. user clicks:
http://www.zurich.ibm.com/RZ.html

2. transfer of one or several documents

Web server S1

3. user clicks on link in new document

Web server S2

4. transfer of one or several documents

back

6

URLs

■ identify documents to be transferred and application layer protocol to use

http://www.zurich.ibm.com/RZ.html

protocol
to be   *target host*
used
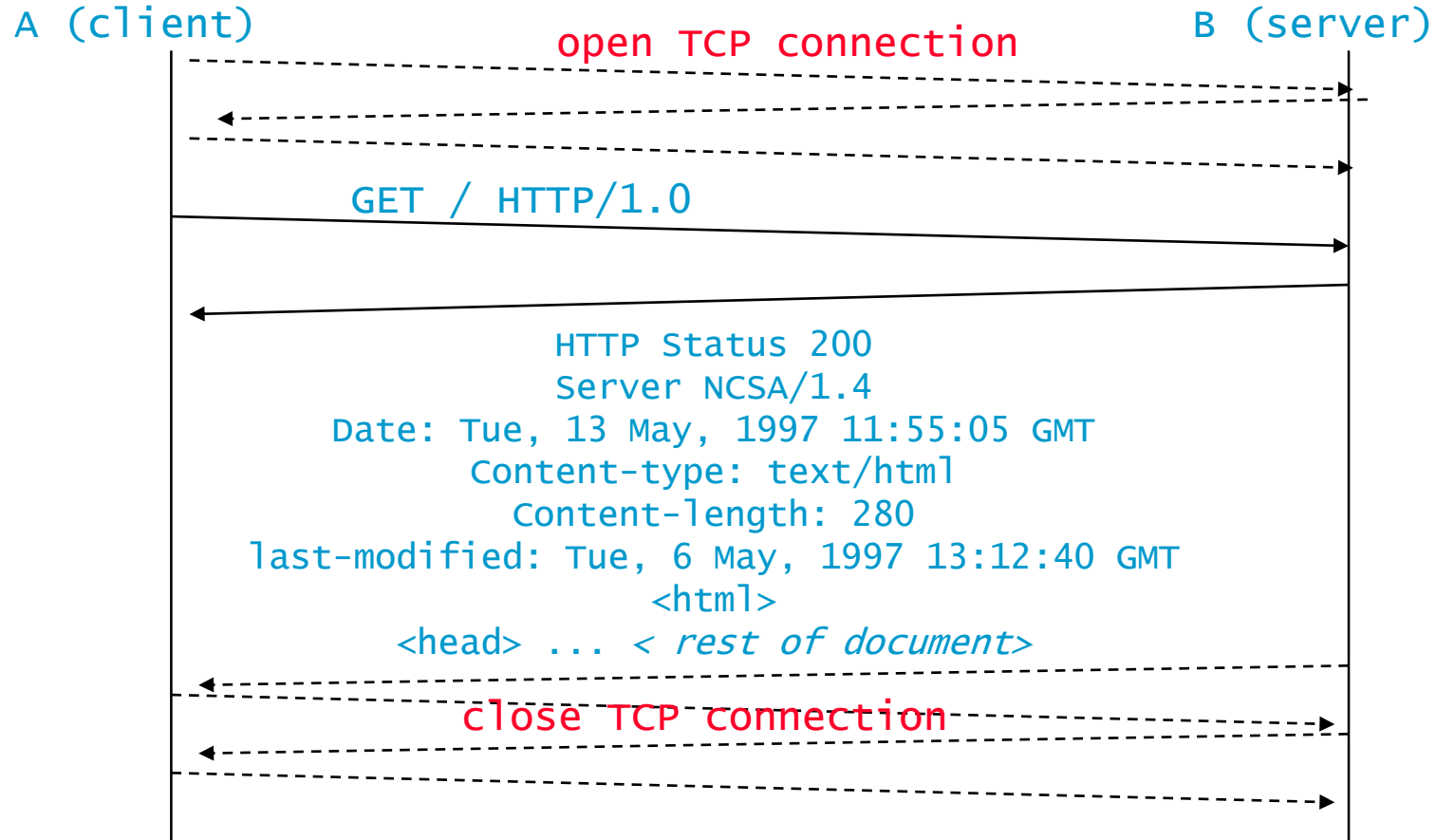
                         path for document on target host

■ examples

▶ ftp://lrcftp.epfl.ch/meinx.ps.gz

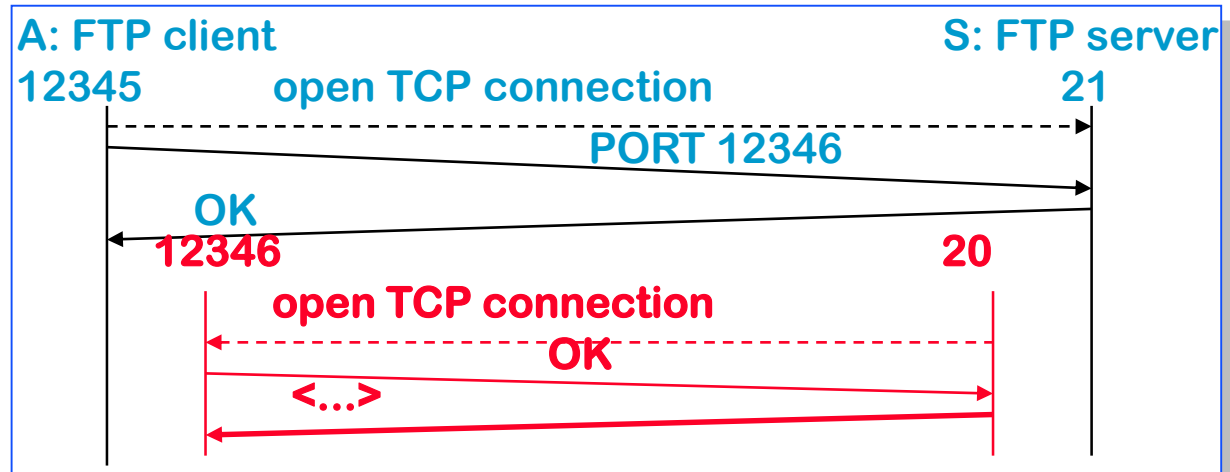▶ http://lrcsuns.epfl.ch:12345

▶ news://comp.infosystems.www

Q. What does 12345 represent ?
solution

HTTP uses TCP

A (client)   B (server)

open TCP connection

GET / HTTP/1.0

HTTP Status 200
Server NCSA/1.4
Date: Tue, 13 May, 1997 11:55:05 GMT
Content-type: text/html
Content-length: 280
last-modified: Tue, 6 May, 1997 13:12:40 GMT
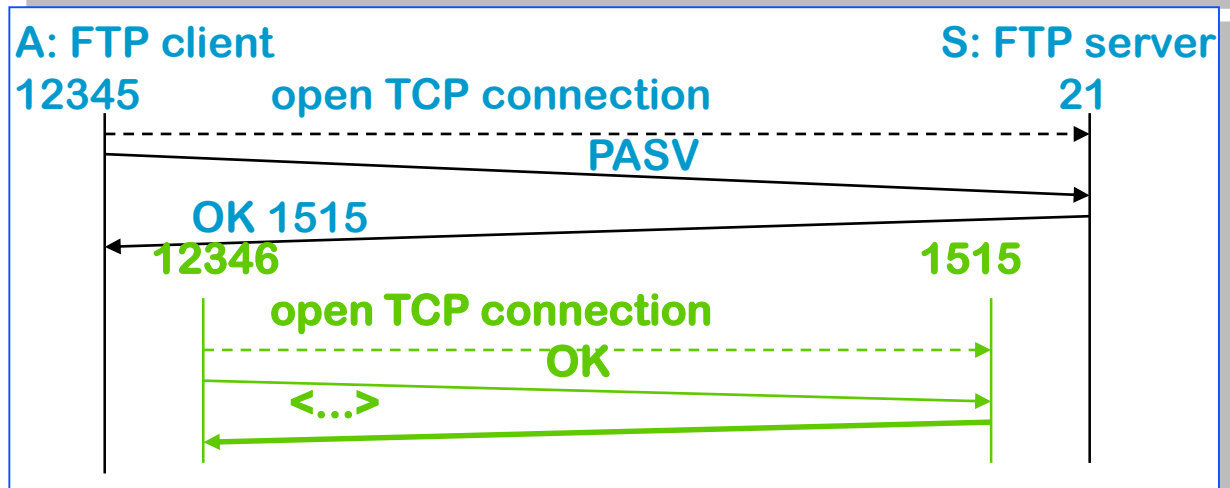<html>
<head> ... < rest of document>

close TCP connection

8

Example: File Transfer Protocol (FTP)

- "active mode": uses two TCP connections; ports 20 and 21 are reserved (first version)

A: FTP client
12345 — open TCP connection — **S: FTP server** 21

PORT 12346

OK
12346 — **20**

open TCP connection
OK
<...>

- "passive-mode" only port 20 is reserved (second version)

A: FTP client
12345 — open TCP connection — **S: FTP server** 21

PASV

OK 1515
12346 — **1515**

open TCP connection
OK
<...>

Q1. What are the TCP server ports in each case ?
  solution

9

Example: Domain Name System: DNS

■ *Why* invented ?

▶ support user friendly naming of resources: computers, printers, mailboxes,…
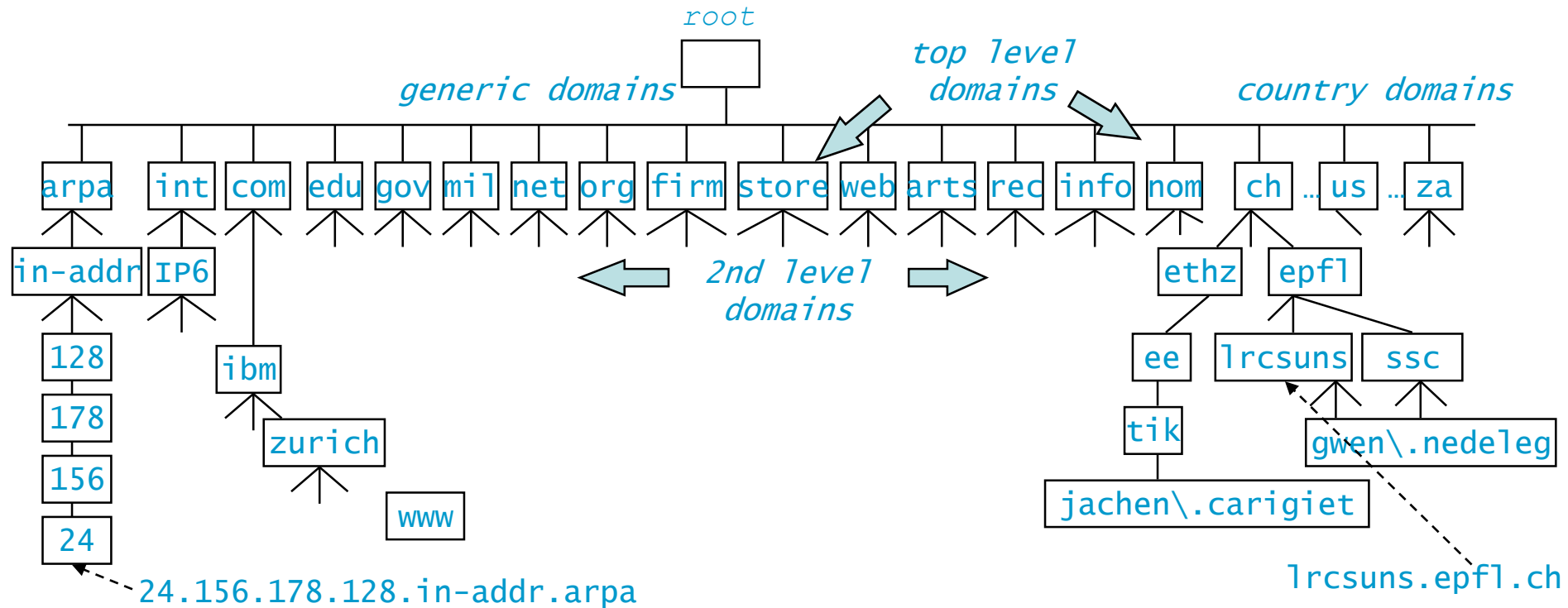
▶ hide IP address changes on servers

Q. Why would an IP address change ?
solution

■ *What* does it do ?

▶ map DNS names (ex: ssc.epfl.ch) to IP addresses

■ *How* does it work ?

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DNS Names

- ▶ every node on the tree represents one or a set of resources
- ▶ every node on the tree has a label(`lrcsuns`) and a domain name (`lrcsuns.epfl.ch`)
- ▶ domain name = sequence of labels, $\leq$ 64 bytes per label
  - ▶ examples: www.zurich.ibm.com, lrcsuns.epfl.ch, ezinfo.ethz.ch, ee.ethz.ch
  - ▶ names have same syntax for subdomains or individual resources

How Does DNS Work ?
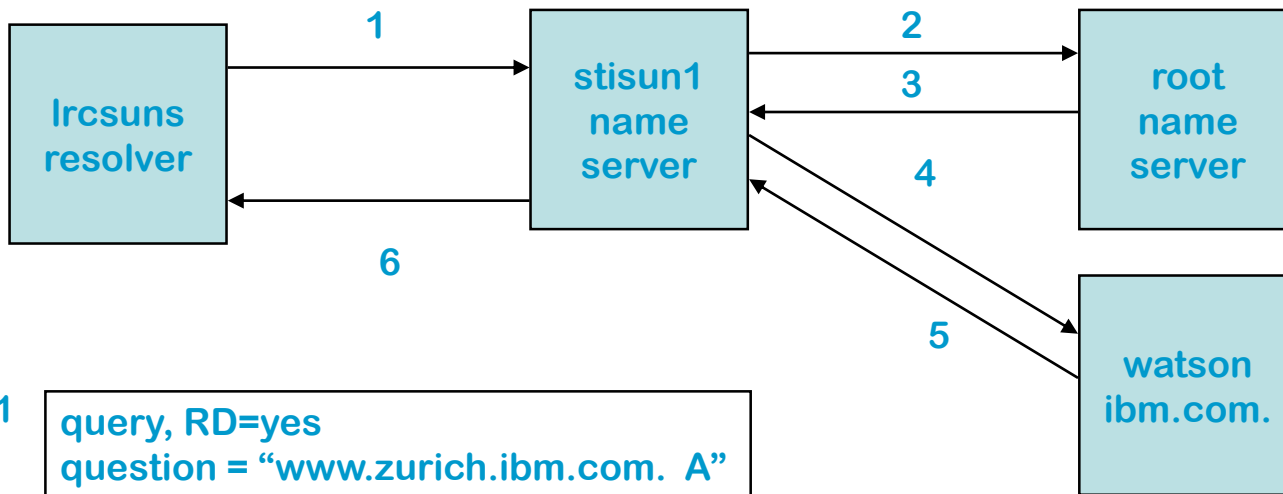
■ When machine needs to map name to IP address

▶ DNS resolver contacts a DNS server

▶ IP address of DNS server is known to machine at configuration time

▶ DNS server may not know answer: in such a case, DNS serves needs to do several iterations, as shown next on an example.

▶ A cache is used at DNS resolver and at DNS server to avoid repeating the same requests frequently.

■ DNS uses UDP for queries and responses.

The next slide shows an example of name resolution.

1. an application on lrcsuns requests a name resolution (find the IP address of www.zurich.ibm.com), a request is sent to the name server configured at lrcsuns

2. the epfl name server does not know the answer, but, as any name server, knows the IP address of root name servers.

3. a root name server knows the IP addresses of all level-2 domains. Thus, it informs lrcsuns of the IP address of the name servers responsible for the ibm.com domain

4. the epfl name server sends the same request now to the ibm name server

5 the ibm name server gives the IP address of www.zurich.ibm.com back to the epfl name server. The epfl name server keeps the address in its cache, this will be used if the same request comes again

6 the epfl name server gives the IP address of www.zurich.ibm.com back to lrcsuns. End of the resolution !

The request sent by lrcsuns is *recursive* (RD=yes): lrcsuns will receive only the final answer. In contrast, the request sent by the epfl name server is *iterative* (RD=no): it receives only partial answers that help towards the solution.

lrcsuns resolver → (1) → **stisun1 name server** → (2) → **root name server**

root name server → (3) → **stisun1 name server**

stisun1 name server → (4) → **root name server**

stisun1 name server ↔ (5) ↔ **watson ibm.com.**

stisun1 name server → (6) → **lrcsuns resolver**

1
```
query, RD=yes
question = "www.zurich.ibm.com.  A"
```

2,4
```
query, RD=no
question = "www.zurich.ibm.com.  A"
```

3
```
answer
question = "www.zurich.ibm.com.     A"
answer = ""
autority= "ibm.com.   NS  watson.ibm.com.
              NS  ns.austin.ibm.com.
              NS  ns.almaden.ibm.com."
additional="watson.ibm.com.    A 192.35.232.34
      ns.austin.ibm.com. A 129.34.139.4
      ns.almaden.ibm.com A 198.4.83.134"
```

5,6
```
answer
question = "www.zurich.ibm.com.    A"
answer = "www.zurich.ibm.com.   A  193.5.61.131"
```
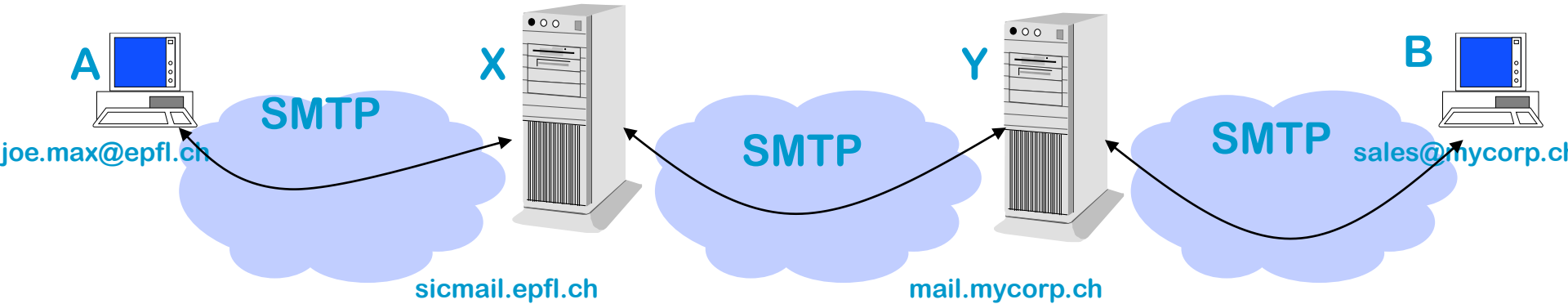
2. Application Layer Gateways

■ Reminder: a layer-*n* *intermediate system* acts on data of protocol *n* for which it is neither source nor destination. The opposite is *end-system*

Q1. What is the name for an IP layer intermediate system ? MAC layer? Physical layer ?
<u>solution</u>

■ An *application layer gateway* is the name for an application layer intermediate system.

▶ It terminates the TCP connections (if the application layer uses TCP)
▶ We have called this in the introduction "store and forward"

Examples of Application Layer Gateways

A
joe.max@epfl.ch
SMTP

X
sicmail.epfl.ch
SMTP

Y
mail.mycorp.ch
SMTP

B
sales@mycorp.ch

■ For example, a mail server acts as application layer gateway when it relays an email from one machine to another.

Q. SMTP uses TCP; **h**ow many TCP connections are there on the figure ?
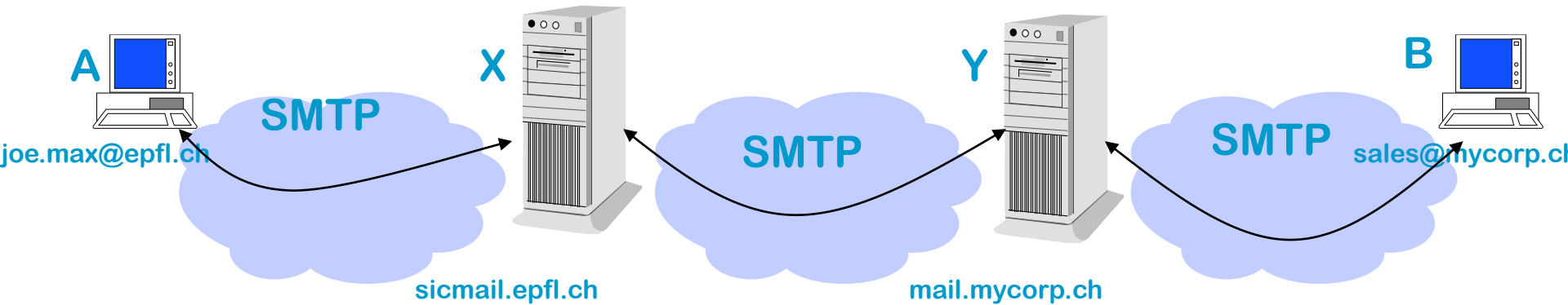solution

The "End-to-end" Principle

■ The "end-to-end" principle of the Internet says that the application layer should avoid intermediate systems, as much as possible.

　► Example: the web

■ *Why* this principle ?

　► Simplify the network. The network is independent of applications and can be run more safely.

　► Allow easy deployment of applications. Ex: the web was deployed in 1994 in a few months. Before that, TCP/IP existed, but not HTTP.

　► Performance is better – see archi.ppt

The "End-to-end" Principle for Email

A — joe.max@epfl.ch
X — sicmail.epfl.ch
SMTP
SMTP
Y — mail.mycorp.ch
SMTP
B — sales@mycorp.ch

■ **Q.** what would a strict application of the end-to-end principle on the figure give ?
solution

18

The End-to-end Principle is not always Applicable

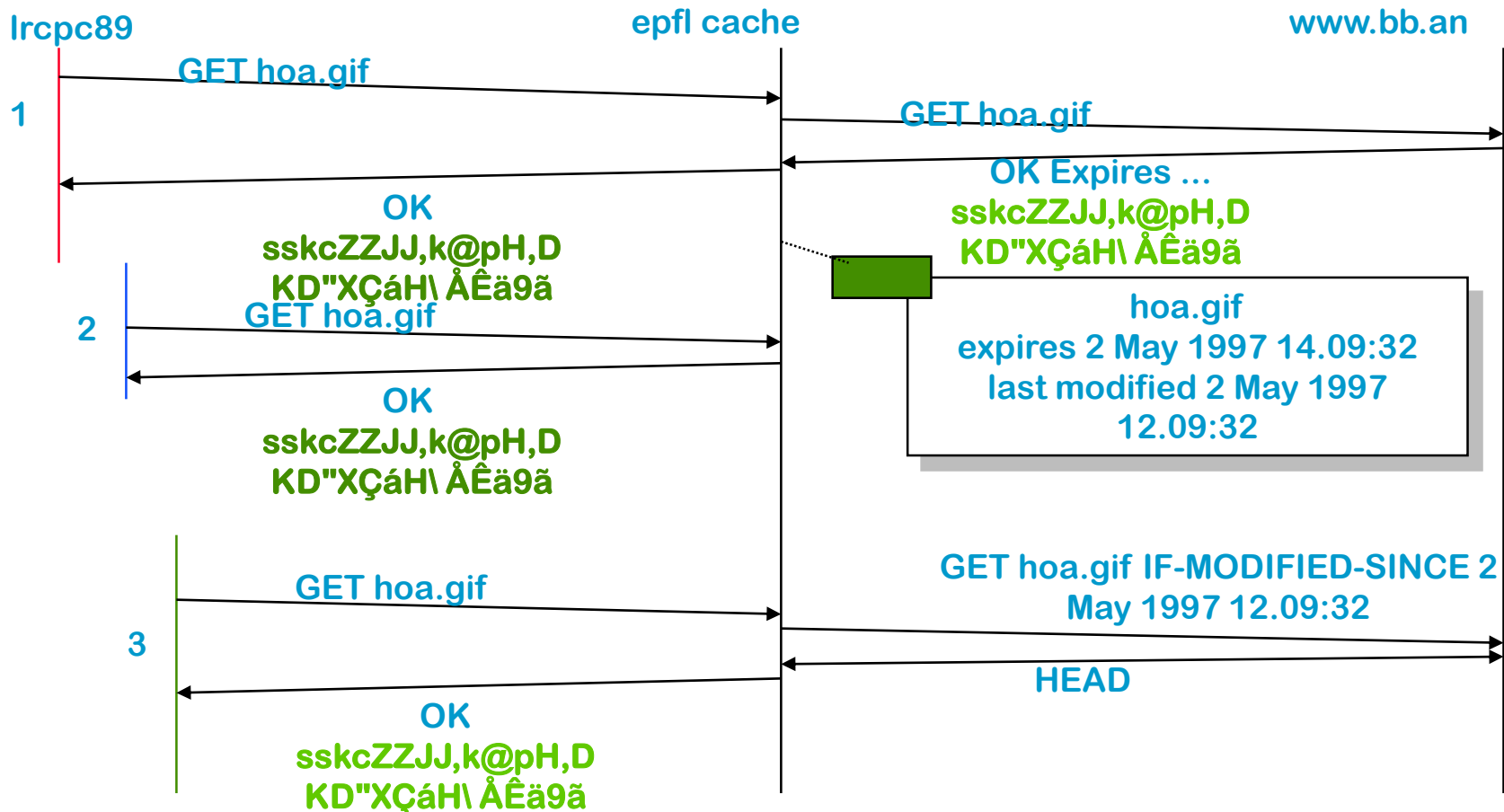■ Application layer gateways are still desirable in some cases.

Q. Can you mention three good reasons for desiring an application layer gateway ?

[solution](#)

Web Caches

- These are HTTP Intermediate Systems, deployed for performance. The idea is: keep frequently asked documents close to user
  - cache can reduce traffic due to responses or to requests
  - similar system deployed by content distribution networks

lrcpc89   **epfl cache**   **www.bb.an**

1

GET hoa.gif

GET hoa.gif

OK
sskcZZJJ,k@pH,D
KD"XÇáH\ ÅÊä9ã

OK Expires …
sskcZZJJ,k@pH,D
KD"XÇáH\ ÅÊä9ã

2

GET hoa.gif

OK
sskcZZJJ,k@pH,D
KD"XÇáH\ ÅÊä9ã

hoa.gif
expires 2 May 1997 14.09:32
last modified 2 May 1997
12.09:32

3

GET hoa.gif

GET hoa.gif IF-MODIFIED-SINCE 2
May 1997 12.09:32

HEAD

OK
sskcZZJJ,k@pH,D
KD"XÇáH\ ÅÊä9ã

Facts to Remember (5)

■ There are many TCP/IP application layer standards

  ► protocol, data format, programs

■ Application layer runs on hosts, not routers

■ Application layer programs use clear text commands

■ DNS is a world wide distributed data base used for mapping names to IP addresses (and vice versa)

Q. Give three examples of application layer intermediate systems and say why they are justified ?

solution

Solutions

URLs

■ identify documents to be transferred and application layer protocol to use

http://www.zurich.ibm.com/RZ.html

protocol to be used *target host*

path for document on target host

■ examples

▶ ftp://lrcftp.epfl.ch/meinx.ps.gz

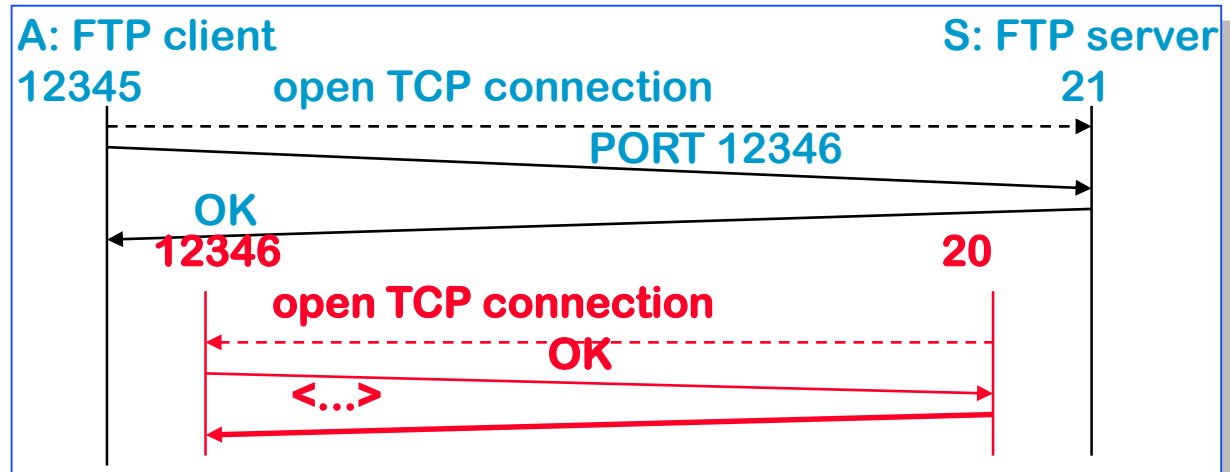▶ http://lrcsuns.epfl.ch:12345

▶ news://comp.infosystems.www

Q. What does 12345 represent ?
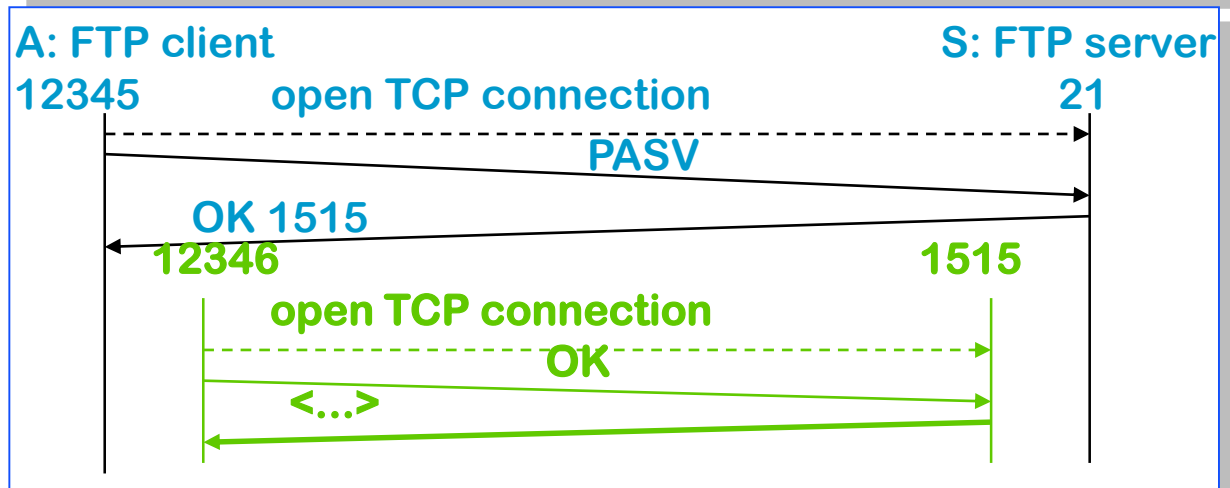**A.** The TCP port number on which the server listens.
back

Example: File Transfer Protocol: FTP

■ "active mode": uses two TCP connections; ports 20 and 21 are reserved (first version)

A: FTP client
12345   open TCP connection   **S: FTP server**
                                                                    21
                            PORT 12346
OK
12346   20
              open TCP connection
                          OK
          <...>

■ "passive-mode" only port 20 is reserved (second version)

A: FTP client
12345   open TCP connection   **S: FTP server**
                                                                    21
                            PASV
OK 1515
12346   1515
              open TCP connection
                          OK
          <...>

Q1. What are the TCP server ports in each case ?

A1. Active mode: port 21 on S; port 12346 on A; Passive mode: port 21 on S. back

Example: Domain Name System: DNS

■ *Why* invented ?

  ▶ support user friendly naming of resources: computers, printers, mailboxes,…

  ▶ hide IP address changes on servers

  Q. Why would an IP address change ?a
  A. For example: you migrate a web server to a new machine. During the migration, you have both machines running, so you need to keep both IP addresses in operation.
  back

■ *What* does it do ?

  ▶ map DNS names (ex: ssc.epfl.ch) to IP addresses

■ *How* does it work ?

2. Application Layer Gateways

■ Reminder: a layer-*n intermediate system* acts on data of protocol *n* for which it is nor source nor destination. The opposite is *end-system*
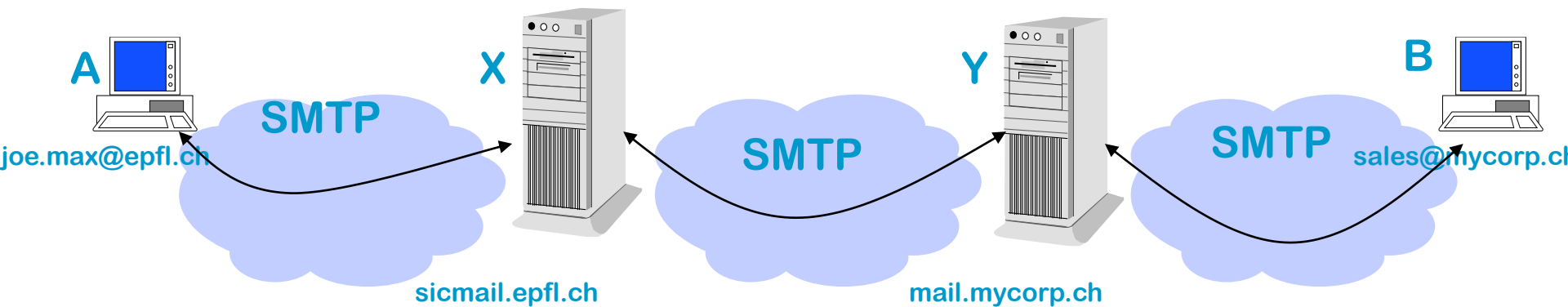
Q1. What is the name for an IP layer intermediate system ? MAC layer? Physical layer ?
A2. router; bridge; repeater   back

■ An *application layer gateway* is the name for an application layer intermediate system.

▸ It terminates the TCP connections (if the application layer uses TCP) and

▸ We have called this in the introduction "store and forward"
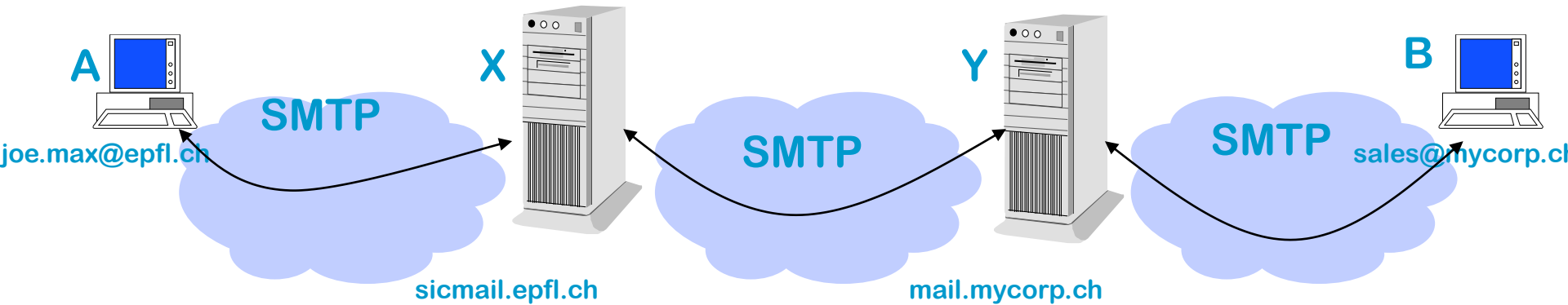
Examples of Application Layer Gateways

■ For example, a mail server acts as application layer gateway when it relays an email from one machine to another.

Q. SMTP uses TCP; **h**ow many TCP connections are there on the figure ?
A. 3

back

The "End-to-end" Principle for Email

A joe.max@epfl.ch

X sicmail.epfl.ch

SMTP

SMTP

SMTP

Y mail.mycorp.ch

B sales@mycorp.ch

■ **Q.** what would a strict application of the end-to-end principle on the previous figure give ?
A. PC A should open a TCP connection directly to B and transfer the email over the connection. This is not possible here as PCs are not expected to be always available for service, as an email server is. However, one could require that A directly opens a TCP connection to email server Y instead of going through email server X.

back

The End-to-end Principle is not always Applicable

■ Application layer gateways are still desirable in some cases.

Q. Can you mention three good reasons for desiring an application layer gateway ?
A. Here are $\geq$ 3 reasons:

1. **Mobility** (or partial connectivity). On the previous figure, this is why we send email to Y and not to B.

2. **Security**. X knows A and accepts email from A, but Y does not know A and does not accept email from A. X knows Y and accepts email from Y. This is why A has to go through X to send email. Similarly, see the module on firewalls

3. **Interworking**. We have seen such a case in the interworking between IPv4 and IPv6.

4. **Performance.** See web proxies

back

Facts to Remember (5)

- There are many TCP/IP application layer standards
  - protocol, data format, programs
- Application layer runs on hosts, not routers
- Application layer programs use clear text commands
- DNS is a world wide distributed data base used for mapping names to IP addresses (and vice versa)

Q. Give three examples of application layer intermediate systems and say why they are justified ?
A.

1. email relay: justified by nomadic users or by authentication
2. web proxies: reduce request rates on hot spot servers; may reduce bandwidth consumption
3. DNS server acting as proxy: reduce amounts of queries by caching