Goal of this Lecture

- Understand what *packet switching* is
- Understand what *circuit switching* is
- Understand their differences
- Understand what a *protocol* is
Outline

- What is the Internet?
- Types of network
- Types of service
- Protocols
- The Internet protocol stack
What is the Internet?
What is the Internet?
What is the Internet?
What is the Internet?

Internet
What is the Internet?

Internet

end system
or host
End Systems

- *End system* or *host* (□)
End system or host (☐)

- a computer
End System or host

- a computer
- a phone (more or less “smart”)
End Systems

- *End system* or *host* (□)
  - a computer
  - a phone (more or less “smart”)
  - a server (well, that would also be a computer)
End Systems

- **End system** or **host** (☐)
  - a computer
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  - a camera (a.k.a., webcam)
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End system or host (☐)

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- a temperature sensor
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- a PDA
End Systems

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- a computer
- a phone (more or less “smart”)
- a server (well, that would also be a computer)
- a camera (a.k.a., webcam)
- a temperature sensor
- a PDA
- ... 
- a car
- a television set
- a picture frame
- a toaster
- ...
End Systems

End system or host

- a computer
- a phone (more or less “smart”)
- a server (well, that would also be a computer)
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- a temperature sensor
- a PDA
- ...
- a car
- a television set
- a picture frame
- a toaster
- ...
- a toilet seat?
- a toothpick?
- ...
What is *Inside* the Internet?
What is *Inside* the Internet?
What is *Inside* the Internet?

- local-area network
- packet switch
What is *Inside* the Internet?

- local-area network
- packet switch
- communication link
The Internet uses *packet switching*
Basic Concepts

- The Internet uses *packet switching*

- *Packet switch*: a *link-layer switch* or a *router*
Basic Concepts

- The Internet uses \textit{packet switching}

- \textit{Packet switch}: a \textit{link-layer switch} or a \textit{router}

- \textit{Communication link}: a connection between packet switches and/or end systems
Basic Concepts

- The Internet uses *packet switching*

- **Packet switch**: a *link-layer switch* or a *router*

- **Communication link**: a connection between packet switches and/or end systems

- **Route**: sequence of switches that a packet goes through (a.k.a. *path*)
Basic Concepts

- The Internet uses *packet switching*

- *Packet switch*: a *link-layer switch* or a *router*

- *Communication link*: a connection between packet switches and/or end systems

- *Route*: sequence of switches that a packet goes through (a.k.a. *path*)

- *Protocol*: control the sending and receiving of information to and from end systems and packet switches
Communication Links

- Various types and forms of medium
Communication Links

- Various types and forms of medium
  - Fiber-optic cable
  - Twisted-pair copper wire
  - Coaxial cable
  - Wireless local-area links (e.g., 802.11, Bluetooth)
  - Satellite channel
  - ...

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Packet Switching
The Internet is a *packet-switched* network
Packet Switching

- The Internet is a *packet-switched* network
- Information is transmitted in *packets*
Packet Switching

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- Information is transmitted in *packets*
- Switches operate on individual packets
The Internet is a *packet-switched* network

Information is transmitted in *packets*

Switches operate on individual packets

A switch (router) receives packets and *forwards* them along to other switches or to end systems
The Internet is a *packet-switched* network.

Information is transmitted in *packets*.

Switches operate on individual packets.

A switch (router) receives packets and *forwards* them along to other switches or to end systems.

Every forwarding decision is taken on the basis of the information contained in the packet.
Circuit Switching
The telephone network is a typical circuit-switched network.
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Communication requires a *connection setup* phase in which the network reserves all the necessary resources for that connection (links, buffers, switches, etc.).
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After a successful setup, the communicating systems are connected by a set of links that are dedicated to their connection for the entire duration of their conversation.
Circuit Switching

- The telephone network is a typical circuit-switched network.

- Communication requires a *connection setup* phase in which the network reserves all the necessary resources for that connection (links, buffers, switches, etc.).

- After a successful setup, the communicating systems are connected by a set of links that are dedicated to their connection for the entire duration of their conversation.

- When the conversation ends, the network tears down the connection, freeing the corresponding resources (links, buffers, etc.) for other connections.
Circuit vs. Packet Switching
Circuit vs. Packet Switching
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Circuit vs. Packet Switching

- Circuit switching requires an expensive setup phase
  - however, once the connection is established, little or no processing is required
Circuit vs. Packet Switching

- Circuit switching requires an expensive setup phase
  - however, once the connection is established, little or no processing is required

- Packet switching does not incur any setup cost
  - however, it always incurs a significant processing and space overhead, on a per-packet basis
    - processing cost for forwarding
    - space overhead because every packet must be self-contained
Circuit vs. Packet Switching (2)
Circuit vs. Packet Switching (2)

- Circuit switching admits a straightforward implementation of quality-of-service guarantees
  - network resources are reserved at connection setup time
Circuit vs. Packet Switching (2)

- Circuit switching admits a straightforward implementation of quality-of-service guarantees
  - network resources are reserved at connection setup time

- Guaranteeing any quality of service with packet switching is very difficult
  - no concept of a “connection”
  - and again, processing, space overhead, etc.
Circuit vs. Packet Switching (3)

- Circuit switching allows only a limited sharing of communication resources
  - once a connection is established, the resources are blocked even though there might be long silence periods
  - i.e., circuit switching is an inefficient way to use the network
Circuit vs. Packet Switching (3)

- Circuit switching allows only a limited sharing of communication resources
  - once a connection is established, the resources are blocked even though there might be long silence periods
  - i.e., circuit switching is an inefficient way to use the network

- Packet switching achieves a much better utilization of network resources
  - it is designed specifically to share links
Virtual Circuits

- Idea: combine the advantages of circuit switching and packet switching
Virtual Circuits

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- There is a connection setup phase
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- Packets carry a virtual circuit identifier instead of the destination address
Virtual Circuits

- Idea: combine the advantages of circuit switching and packet switching

- There is a connection setup phase

- The connection does not create a physical circuit, but rather a “virtual circuit”

- Information is sent in packets, so links can be shared more effectively

- Packets carry a *virtual circuit identifier* instead of the destination address
  - *Important observation*: at any given time there are much fewer connections than destinations
    - much faster per-packet processing (forwarding)
    - lower per-packet space overhead
Virtual Circuit
communication

network
Taxonomy of Networks

communication network

- circuit switching
  - time division multiplexing
  - frequency division multiplexing
- packet switching
Taxonomy of Networks

- Communication network
  - Circuit switching
    - Time division multiplexing
  - Packet switching
    - Frequency division multiplexing
    - Virtual circuit
    - Datagram network
Taxonomy of Networks

- Communication network
  - Circuit switching
    - Time division multiplexing
    - Frequency division multiplexing
  - Packet switching
    - Virtual circuit
    - Datagram network
Service Perspective

local-area network

packet switch
What kind of *service* does the Internet offer to end systems?
Two end systems can communicate through the Internet, but exactly what kind of communication service is that of the Internet?
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**Connectionless, “best effort”**

- the network accepts “datagrams” for delivery—this is conceptually similar to the postal service
- “best effort” really means *unreliable* though not malicious
Two end systems can communicate through the Internet, but exactly what kind of communication service is that of the Internet?

**Connectionless, “best effort”**
- the network accepts “datagrams” for delivery—this is conceptually similar to the postal service
- “best effort” really means *unreliable* though not malicious

**Connection-oriented, reliable**
- virtual duplex communication channel \((A \leftrightarrow B)\)—conceptually similar to a telephone service
- information is transmitted “reliably” and in order
How reliable is a “reliable” service?
How reliable is a “reliable” service?

The term “reliable” means that information will eventually reach its destination if a route is viable within a certain amount of time.
How reliable is a “reliable” service?

The term “reliable” means that information will eventually reach its destination if a route is viable within a certain amount of time.

The network makes absolutely no guarantees on latency (i.e., the time it takes to transmit some information from a source to a destination).
End systems as well as packet switches run protocols. What is a protocol?
End systems as well as packet switches run *protocols*. What is a protocol?

E.g., let’s consider a phone call: Alice calls Bob

![Diagram of a phone call with Alice and Bob exchanging 'hello' messages]
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E.g., let’s consider a phone call: Alice calls Bob

Alice → Bob: hello
Bob → Alice: hello, this is Alice
Alice → Bob: Alice, what’s up?
Bob → Alice: bla, bla...
End systems as well as packet switches run *protocols*. What is a protocol?

E.g., let’s consider a phone call: Alice calls Bob

Alice

hello

hello, *this is* Alice

Alice, what’s up?

bla, bla...

okay, bye

Bob
End systems as well as packet switches run protocols. What is a protocol?

E.g., let’s consider a phone call: Alice calls Bob
Communication Protocols

- Phases of the protocol
  - *handshake*: establishes the identities and/or the context
  - *conversation*: free-form exchange
  - *closing*: terminates the conversation
Communication Protocols

- Phases of the protocol
  - *handshake*: establishes the identities and/or the context
  - *conversation*: free-form exchange
  - *closing*: terminates the conversation

- This protocol assumes a connection-oriented medium

- The protocol involves two parties (Alice and Bob)

- ...
Another example: air traffic control
Another example: air traffic control

- ...United 971, turn left heading 2-7-0
Another example: air traffic control

- ...United 971, turn left heading 2-7-0
- left to 2-7-0, United 971
Another example: air traffic control

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- ...Alitalia 631, contact Malpensa approach at 119.20
Communication Protocols (2)

- Another example: air traffic control
  - . . . United 971, turn left heading 2-7-0
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  - 1-1-9 point 2-0, Alitalia 631, ciao
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  - ...Center, request, Delta 800
  - ...United 971, climb and maintain flight level 3-7-0
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- flight level 3-7-0, United 971
- ...Delta 800, go ahead
Communication Protocols (2)

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- flight level 3-7-0, United 971
- ...Delta 800, go ahead
- requesting flight level 3-5-0, Delta 800
Communication Protocols (2)

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- ...United 971, climb and maintain flight level 3-7-0
- flight level 3-7-0, United 971
- ...Delta 800, go ahead
- requesting flight level 3-5-0, Delta 800
- Delta 800, unable at the moment
Communication Protocols (2)
Communication Protocols (2)

- A connectionless protocol
Communication Protocols (2)

- A connectionless protocol
- Multi-party communication
Communication Protocols (2)

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- Timeout and retransmission
Communication Protocols (2)

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- Multi-party communication
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- Interleaved communication
- Acknowledgements
- Timeout and retransmission
- “Master” role
Communication Protocols (3)

Let’s revisit the phone-call protocol

Alice

Bob
Let’s revisit the phone-call protocol.
Let’s revisit the phone-call protocol

Alice

Bob

hello

hello, this is Alice
Let’s revisit the phone-call protocol

Alice

Bob

hello

hello, this is Alice

Alice who?
Let’s revisit the phone-call protocol

Alice

hello

hello, this is Alice

Alice who?

Bob

sorry, wrong number

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Another run of the phone-call protocol
Another run of the phone-call protocol

Alice

hello

Bob
Another run of the phone-call protocol

Alice  Bob

- hello
- hello?
Another run of the phone-call protocol

Alice

Bob

hello

hello?

anybody there?
Communication Protocols: Principles

- A protocol is a lot like a program
  - in fact, it is a *distributed program*, where different processes can send messages to each other
A protocol is a lot like a program

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It is an *executable* specification
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It must be *unambiguous*
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- It must be *complete*
  - i.e., it must include actions and/or responses for all possible situations and all possible messages
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It must be *complete*
  ▶ i.e., it must include actions and/or responses for all possible situations and all possible messages

A network protocol must also define all the necessary *message formats*
Another protocol: deciding where to go for dinner
Another protocol: deciding where to go for dinner

Alice

Bob

how about pizza?
Another protocol: deciding where to go for dinner

Alice

how about pizza?

Bob

we did that already
Another protocol: deciding where to go for dinner

Alice

how about pizza?

we did that already

Bob

okay, you decide
Another protocol: deciding where to go for dinner

Alice: how about pizza?
Bob: we did that already
Alice: okay, you decide
Bob: uhm... er...
Communication Protocols (5)

Another protocol: deciding where to go for dinner

Alice

how about pizza?

we did that already

okay, you decide

uhm... er...

Bob

so?
Another protocol: deciding where to go for dinner

Alice

how about pizza?

we did that already

okay, you decide

uhm... er...

Bob

so?

let's just do pizza
Alice calls Bob to decide where to go for dinner
Alice calls Bob to decide where to go for dinner.
Alice calls Bob to decide where to go for dinner.
Alice calls Bob to decide where to go for dinner

Alice

hello

hello, this is Alice

Bob
Alice calls Bob to decide where to go for dinner

Alice: hello
Bob: hello, this is Alice
Alice: Alice, what’s up?
Alice calls Bob to decide where to go for dinner.

Alice: hello
Bob: hello, this is Alice
Alice: Alice, what’s up?
Bob: let’s go out to dinner
Alice calls Bob to decide where to go for dinner

Alice

hello

Bob

hello, this is Alice

Alice, what’s up?

let’s go out to dinner

“where to go for dinner” protocol...
Alice calls Bob to decide where to go for dinner

Alice

Bob

hello

hello, this is Alice

Alice, what’s up?

let’s go out to dinner

“where to go for dinner” protocol...

okay, bye
Alice calls Bob to decide where to go for dinner

Alice

Bob

hello

hello, this is Alice

Alice, what’s up?

let’s go out to dinner

“where to go for dinner” protocol...

okay, bye

bye
Alice calls Bob to decide where to go for dinner
Alice calls Bob to decide where to go for dinner

phone call protocol
Alice calls Bob to decide where to go for dinner

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Internet Protocol Stack
application
Internet Protocol Stack

- application
- transport
Internet Protocol Stack

(application

transport

network)
Internet Protocol Stack

- application
- transport
- network
- link
Internet Protocol Stack

- application
- transport
- network
- link
- physical
Internet Protocol Stack (2)

- *Application* (e.g., HTTP, SMTP, and DNS)
  - application functionalities
  - application messages
Internet Protocol Stack (2)

- **Application** (e.g., HTTP, SMTP, and DNS)
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- **Transport** (e.g., TCP and UDP)
  - application multiplexing, reliable transfer (TCP), congestion control (TCP)
  - datagrams (UDP) or segments (TCP)
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Network (IP)
  ▶ end to end datagram, best-effort service, routing, fragmentation
  ▶ packets (IP)
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  - point-to-point or local broadcast communication
  - frames (or packets)
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- **Physical**