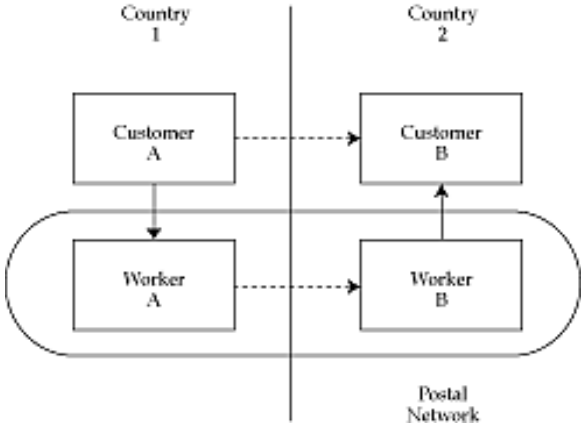
Protocol Layering

An Engineering Approach to Computer Networking

Peer entities



- Customer A and B are *peers*
- Postal worker A and B are *peers*

Protocols

- A *protocol* is a set of rules and formats that govern the communication between communicating peers
  - set of valid messages
  - meaning of each message
- A protocol is necessary for any function that requires cooperation between peers

Example

- Exchange a file over a network that corrupts packets
  - but doesn't lose or reorder them
- A simple protocol
  - send file as a series of packets
  - send a *checksum*
  - receiver sends OK or not-OK message
  - sender waits for OK message
  - if no response, resends entire file
- Problems
  - single bit corruption requires retransmission of entire file
  - what if link goes down?
  - what if not-OK message itself is corrupted?

What does a protocol tell us?

- *Syntax* of a message
  - what fields does it contain?
  - in what format?
- *Semantics* of a message
  - what does a message mean?
  - for example, not-OK message means receiver got a corrupted file
- *Actions* to take on receipt of a message
  - for example, on receiving not-OK message, retransmit the entire file

Another way to view a protocol

- As providing a *service*
- The example protocol provides *reliable file transfer service*
- Peer entities use a protocol to provide a service to a higher-level peer entity
  - for example, postal workers use a protocol to present customers with the abstraction of an *unreliable letter transfer* service

Protocol layering

- A network that provides many services needs many protocols
- Turns out that some services are independent
- But others depend on each other
- Protocol A may use protocol B as a *step* in its execution
  - for example, packet transfer is one step in the execution of the example reliable file transfer protocol
- This form of dependency is called *layering*
  - reliable file transfer is *layered* above packet transfer protocol
  - like a subroutine

Some terminology

- *Service access point (SAP)*
  - interface between an upper layer and a lower layer
- *Protocol data units (PDUs)*
  - packets exchanged between peer entities
- *Service data units (SDUs)*
  - packets handed to a layer by an upper layer
- PDU = SDU + optional header or trailer
- Example
  - letter transfer service
  - protocol data unit between customers = letter
  - service data unit for postal service = letter
  - protocol data unit = mailbag (aggregation of letters)
  - (what is the SDU header?)

Protocol stack

- A set of protocol layers
- Each layer uses the layer below and provides a service to the layer above
- Key idea
  - once we define a service provided by a layer, we need know nothing more about the details of *how* the layer actually implements the service
  - information hiding
  - decouples changes

The importance of being layered

- Breaks up a complex problem into smaller manageable pieces
  - can compose simple service to provide complex ones
  - for example, WWW (HTTP) is Java layered over TCP over IP (and uses DNS, ARP, DHCP, RIP, OSPF, BGP, PPP, ICMP)
- Abstraction of implementation details
  - separation of implementation and specification
  - can change implementation as long as service interface is maintained
- Can reuse functionality
  - upper layers can share lower layer functionality
  - example: WinSock on Microsoft Windows

Problems with layering

- Layering hides information
  - if it didn't then changes to one layer could require changes everywhere
    - *layering violation*
- But sometimes hidden information can be used to improve performance
  - for example, flow control protocol may think packet loss is always because of network congestion
  - if it is, instead, due to a lossy link, the flow control breaks
  - this is because we hid information about reason of packet loss from flow control protocol

Layering

- There is a tension between information-hiding (abstraction) and achieving good performance
- Art of protocol design is to leak enough information to allow good performance
  - but not so much that small changes in one layer need changes to other layers

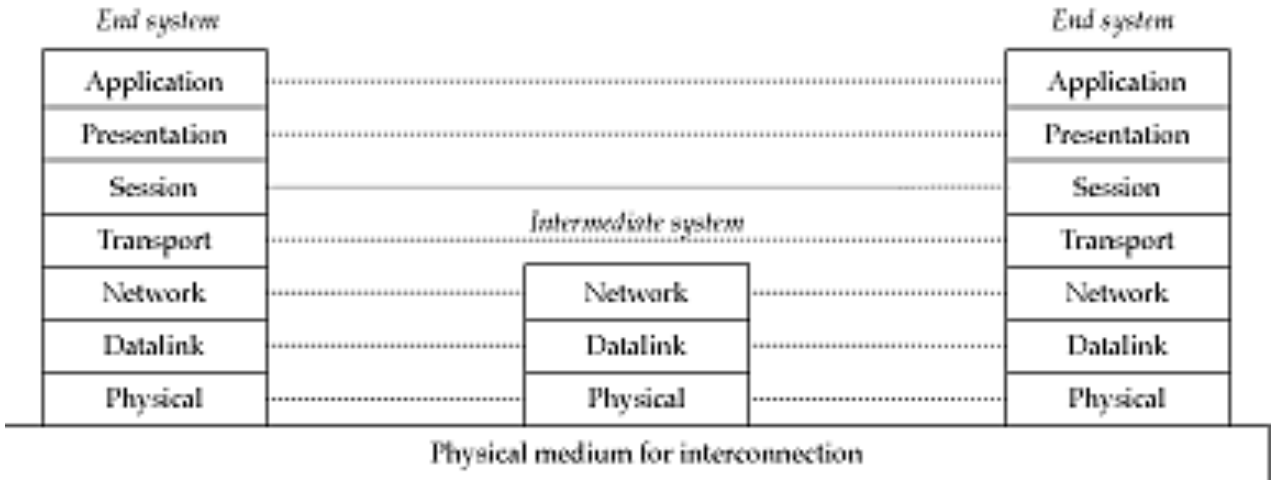
ISO OSI reference model

- A set of protocols is *open* if
  - protocol details are publicly available
  - changes are managed by an organization whose membership and transactions are open to the public
- A system that implements open protocols is called an *open system*
- International Organization for Standards (ISO) prescribes a standard to connect open systems
  - *open system interconnect (OSI)*
- Has greatly influenced thinking on protocol stacks

ISO OSI

- *Reference model*
  - formally defines what is meant by a layer, a service etc.
- *Service architecture*
  - describes the services provided by each layer and the service access point
- *Protocol architecture*
  - set of protocols that implement the service architecture
  - compliant service architectures may still use non-compliant protocol architectures

The seven layers



Physical layer

- Moves bits between physically connected end-systems
- Standard prescribes
  - coding scheme to represent a bit
  - shapes and sizes of connectors
  - bit-level synchronization
- Postal network
  - technology for moving letters from one point to another (trains, planes, vans, bicycles, ships…)
- Internet
  - technology to move bits on a wire, wireless link, satellite channel etc.
- Relevant theory: Information, Modulation, Coding
  - Nyquist, Shannon
- See also Digital Signal Processing next term

Datalink layer

- Introduces the notion of a *frame*
  - set of bits that belong together
- *Idle* markers tell us that a link is not carrying a frame
- *Begin* and *end* markers delimit a frame
- On a broadcast link (such as Ethernet)
  - end-system must receive only bits meant for it
  - need datalink-layer address
  - also need to decide who gets to speak next
  - these functions are provided by *Medium Access sublayer (MAC)*
- Some data links also retransmit corrupted packets and pace the rate at which frames are placed on a link
  - part of *logical link control sublayer*
  - layered over MAC sublayer
- Relevant Theory: Information Theory Shannon, and Coding

Datalink layer (contd.)

- Datalink layer protocols are the first layer of software
- Very dependent on underlying physical link propeties
- Usually bundle both physical and datalink layer on *host adaptor card*
  - example: Ethernet
- Postal service
  - mail bag ‘frames’ letters
- Internet
  - a variety of datalink layer protocols
  - most common is Ethernet
  - others are FDDI, SONET, HDLC

Network layer

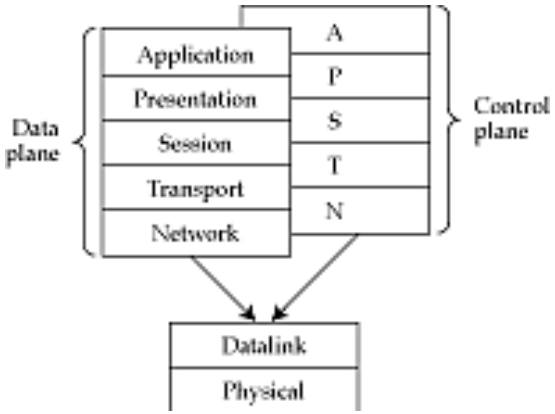
- Logically concatenates a set of links to form the abstraction of an end-to-end link
- Allows an end-system to communicate with any other end-system by computing a route between them
- Hides idiosyncrasies of datalink layer
- Provides unique network-wide addresses
- Found both in end-systems and in intermediate systems
- At end-systems primarily hides details of datalink layer
  - segmentation and reassembly
  - error detection
- Relevant Theory: Graph theory, queueing theory
- Why not Kruskal,Prim etc - see later, but nets evolve, they are not designed much any more

Network layer (contd.)

- At intermediate systems
  - participates in routing protocol to create routing tables
  - responsible for forwarding packets
  - scheduling the transmission order of packets
  - choosing which packets to drop

Two types of network layers

- In datagram networks
  - provides both routing and data forwarding
- In connection-oriented network
  - we distinguish between data plane and control plane
  - data plane only forwards and schedules data (touches every byte)
  - control plane responsible for routing, call-establishment, call-teardown (doesn't touch data bytes)



Network layer

- Postal network
  - set up internal routing tables
  - forward letters from source to destination
  - static routing
  - multiple qualities of service
- Internet
  - network layer is provided by Internet Protocol
  - found in all end-systems and intermediate systems
  - provides abstraction of end-to-end link
  - segmentation and reassembly
  - packet-forwarding, routing, scheduling
  - unique IP addresses
  - can be layered over anything, but only best-effort service

Transport layer

- Network provides a ‘raw’ end-to-end service
- Transport layer creates the abstraction of an *error-controlled*, *flow-controlled* and *multiplexed* end-to-end link
- Error control
  - message will reach destination despite packet loss, corruption and duplication
  - retransmit lost packets; detect, discard, and retransmit corrupted packets; detect and discard duplicated packets
- Flow control
  - match transmission rate to the currently sustainable rate on the path to destination, and at the destination itself
- Relevant theory: Control Theory and Optimisation

Transport layer (contd.)

- Multiplexes multiple applications to the same end-to-end connection
  - adds an application-specific identifier (*port number)* so that receiving end-system can hand in incoming packet to the correct application
- Some transport layers provide fewer services
  - e.g. simple error detection, no flow control, and no retransmission
  - *lightweight transport layer*

Transport layer (contd.)

- Postal system
  - doesn't have a transport layer
  - implemented, if at all, by customers
  - detect lost letters (how?) and retransmit them
- Internet
  - two popular protocols are TCP and UDP
  - TCP provides error control, flow control, multiplexing
  - UDP provides only multiplexing

Session layer

- Not common
- Provides *full-duplex service, expedited data delivery,* and *session synchronization*
- Duplex
  - if transport layer is simplex, concatenates two transport endpoints together
- Expedited data delivery
  - allows some messages to skip ahead in end-system queues, by using a separate low-delay transport layer endpoint
- Synchronization
  - allows users to place marks in data stream and to roll back to a prespecified mark

Example

- Postal network
  - suppose a company has separate shipping and receiving clerks
  - chief clerk can manage both to provide abstraction of a duplex service
  - chief clerk may also send some messages using a courier (expedited service)
  - chief clerk can arrange to have a set of messages either delivered all at once, or not at all
- Internet
  - doesn't have a standard session layer
  - (HTTP 1.1 ++)

Presentation layer

- Unlike other layers which deal with *headers* presentation layer touches the application data
- Hides data representation differences between applications
  - e.g. *endian-ness*
- Can also encrypt data
- Usually *ad hoc*
- Postal network
  - translator translates contents before giving it to chief clerk
- Internet
  - no standard presentation layer
  - only defines network byte order for 2- and 4-byte integers
- Processor Architecture, Programmign Language, Storage and OS independence.

Application layer

- The set of applications that use the network
- Doesn't provide services to any other layer
- Postal network
  - the person who uses the postal system
  - suppose manager wants to send a set of recall letters
  - translator translates letters going abroad
  - chief clerk sends some priority mail, and some by regular mail
  - mail clerk sends a message, retransmits if not acked
  - postal system computes a route and forwards the letters
  - datalink layer: letters carried by planes, trains, automobiles
  - physical layer: the letter itself

Layering

- We have broken a complex problem into smaller, simpler pieces
- Provides the application with *sophisticated* services
- Each layer provides a clean abstraction to the layer above

Why seven layers?

- Need a top and a bottom -- 2
- Need to hide physical link, so need datalink -- 3
- Need both end-to-end and hop-by-hop actions; so need at least the network and transport layers -- 5
- Session and presentation layers are not so important, and are often ignored
- So, we need at least 5, and 7 seems to be excessive
- Note that we can place functions in different layers