Networking: functional elements

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Outline

- Networking as resource sharing
- Functional elements
  - Multiplexing
  - Switching
  - Routing
  - Network management

  - Traffic controls and timescales

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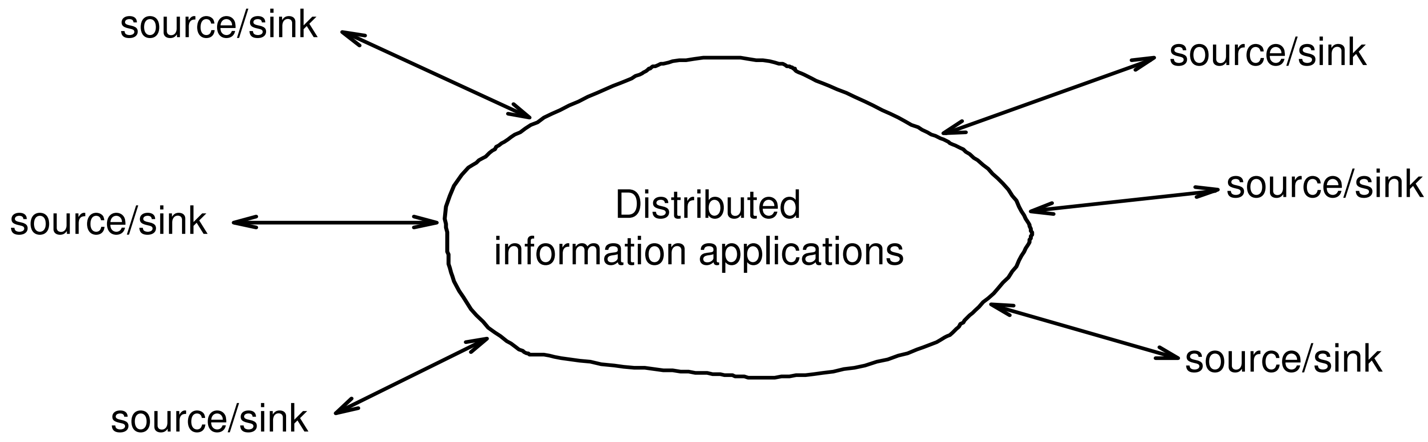
Networking

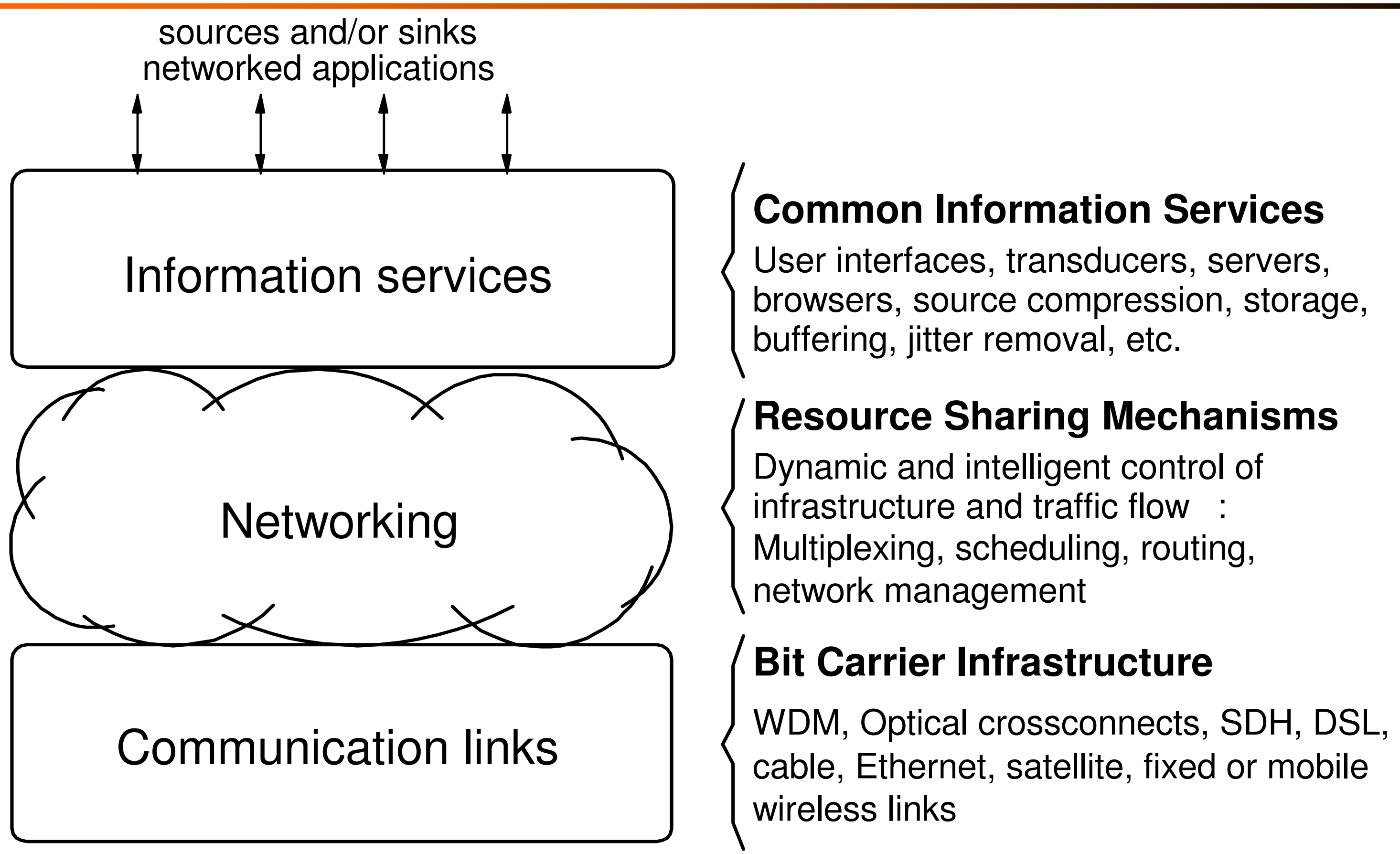
- Information technology is as much about *manipulating* information as about moving or *transporting* information
- Networking deals with *Information Transport*. More specifically, the mechanisms that govern the sharing of the resources in the bit carrier infrastructure.

Preliminaries

- Points at which networked information services connect to generators and absorbers of information flow, called *sources* and *sinks* respectively
  - Example sources: telephone transmitters, video cameras, file on a disk
  - Example sinks: telephone receivers, video monitors, storage devices



A layered view



- A three-layered view of a communication network. "Networking" is concerned with *resource sharing mechanisms* that efficiently share the bit carrier infrastructure, and control the quality of service provided to the various applications using the network

A layered view (contd.)

- A layered view helps in identifying and distinguishing different classes of functions
  - Similar to the concept of subroutines or functions in programming
- Three layers
  - Information Services Layer
  - Bit Carrier Infrastructure Layer
  - “Networking” Layer

Information services

- Hardware and software to *facilitate* the transport service and *attach* the source and sink
  - *Encode* information from source into a transportable form and *decode* received information into usable form
  - Examples
    - Voice coding, packet buffering and playout, and voice decoding for packet telephony
    - Mail preparation and forwarding software for electronic mail

Information services (contd.)

- Handle network induced imperfections—loss, delay, delay variations
  - Define the allowable imperfections from the network—Quality of Service (QoS) as statistical (mean, percentiles) or deterministic (bounds) guarantees
  - Example QoS measures: service denial (blocking), delay, delay variations, loss, reordering, etc.

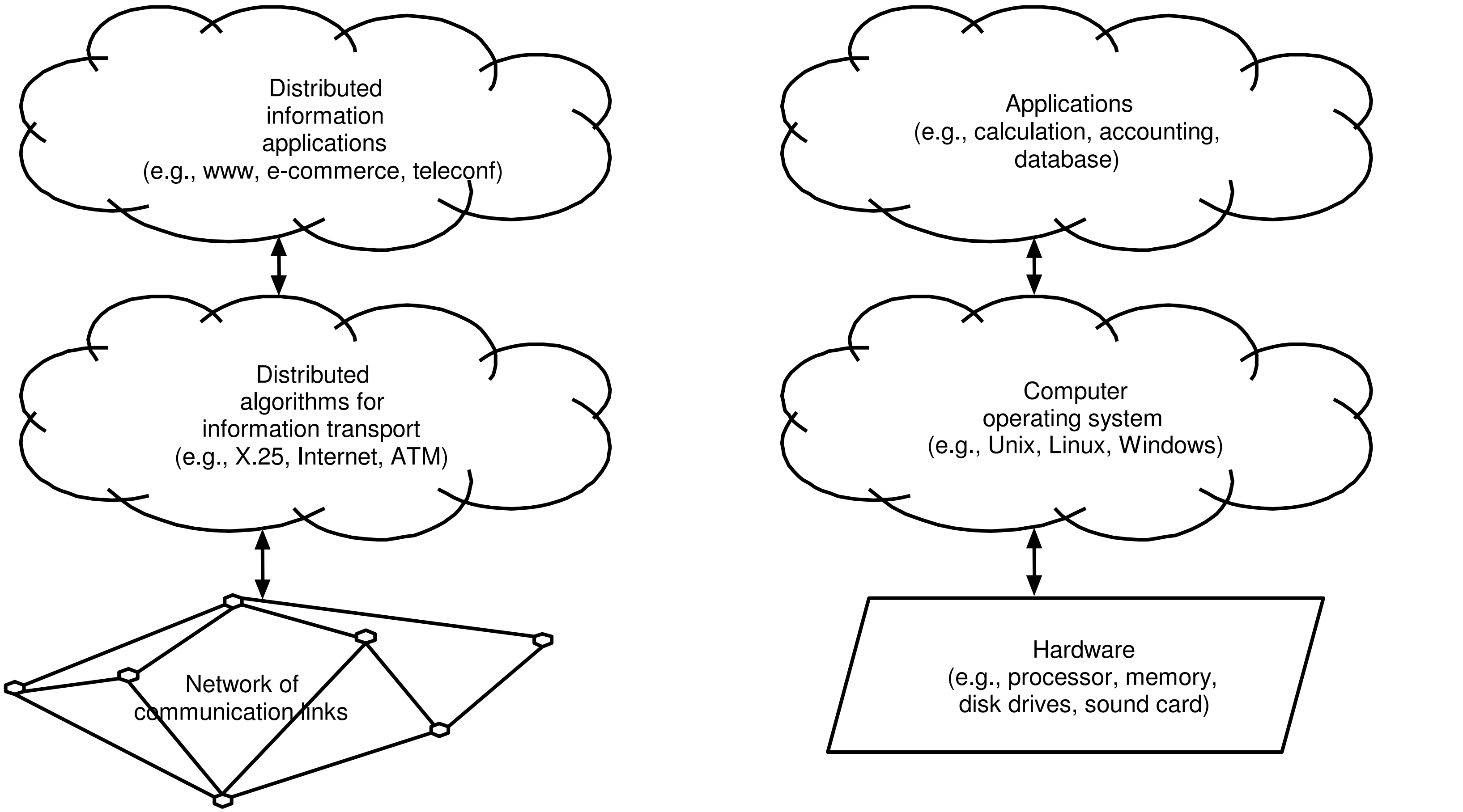
Bit carrier infrastructure

- The raw material for building the information transport superstructure
  - The issues here are those from a classical communication course—modulation, capacity, channel coding, medium characteristics, etc.
  - Reasonable to assume that the channel is digital
  - We assume that the communication links are *imperfect bit pipes* in the sense that these pipes can delay, lose or modify the bits that they carry

Networking

- Uses the raw material of communication links and provides the networking services that the information services assumes
  - The link design problem is concerned with the *bit flow*—extract the maximum bit rate possible, Networking is concerned with *information flow*

Computer OS analogy



- Networking is concerned with distributed algorithms for efficient sharing of bit carrier network resources. Very similar to OS of a computer helping applications to use and share hardware resources

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Functional elements:
consider a sample information flow

- After source prepares the bits for transportation, “network” decides how to *route* flow over physical network
- Infrastructure is shared by many such flows. Hence network has to decide how to *multiplex* this flow with other flows.
- Flow may traverse multiple links. At junction of two links, *switch* flow elements to target link.
- Need to monitor network behavior and collect status information; possibly handle situations for which network is not engineered. i.e., perform *network management*.

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Multiplexing

- Communications links or *bit pipes* are expensive resources and possibly imperfect;

  Need to amortize cost among a large number of sources — need mechanism to share efficiently

- Assume information flow requirements — source and destination and capacity required — is a time varying process

- Sharing the communication link is *multiplexing* — technique used for systematically merging several data flows into one bit-pipe.

- Two types of multiplexing:
  - Circuit multiplexing
  - Packet multiplexing

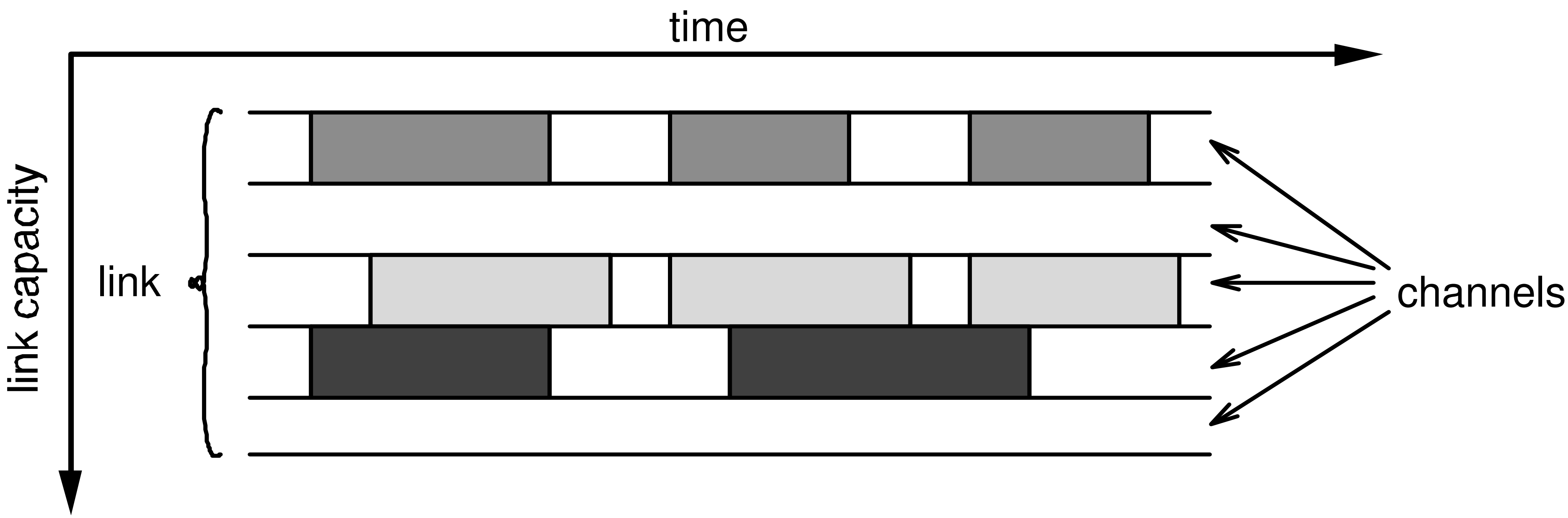
Circuit multiplexing on a link

- Link capacity is statically partitioned into channels (possibly different capacities)—Frequency, Time, Space and Code Division Multiplexing
  - Standards specify partitioning details, e.g., CCITT and North American standards for TDM
- Each conversation (flow) is allocated to a channel for the entire duration of call—the call *holds* the channel
- *Connection setup* is required to allocate resources
  - Fixed rate allocated at time of connection setup determines the peak rate at which the source can transmit data
  - A call (request for resources) can be *blocked* if all the channels are busy

Circuit multiplexing (contd.)

- Performance measures:
  - *Connection setup delay*
  - *Call blocking probability*
- A typical design problem:
  - What should be the link capacity for a given load and specified blocking probability?
- The link may also have to handle different *classes* of flows each with a different blocking probability requirement

Circuit multiplexing: resource allocation model

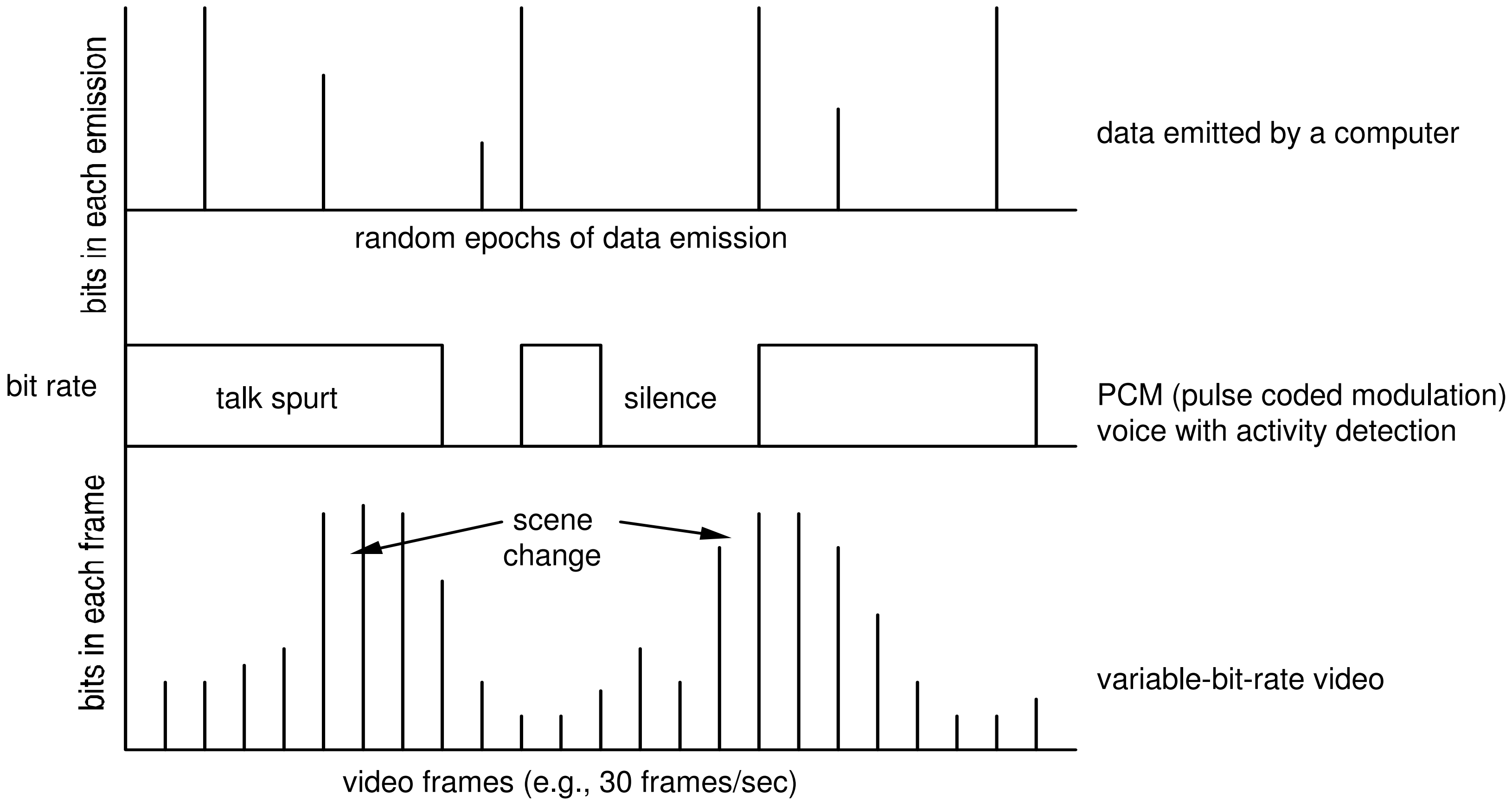


- Static partitioning of bandwidth in a circuit switched network

Inefficiency of circuit multiplexing?

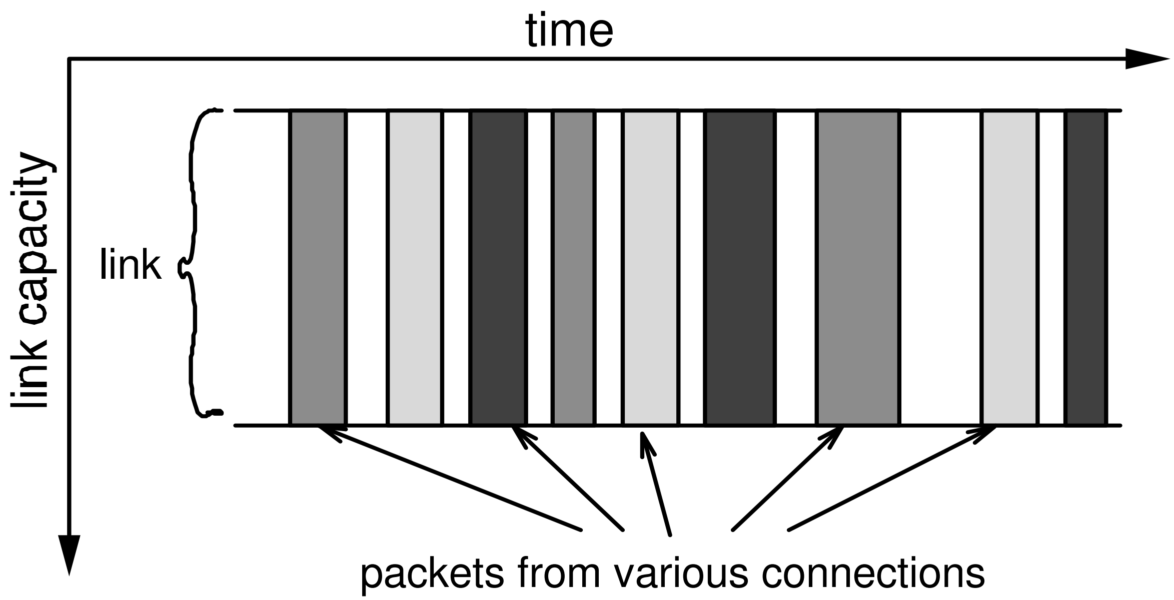
- Most sources generate data in bursts:
  - Voice: Talk and silence spurts
  - Video: Scene changes
  - Telnet: Typing behaviour
  - Web browsing patterns: Think times between downloads

Motivating packet multiplexing



- Traffic flow from sources is typically bursty
  - Average rate is much lower than peak rate
  - Capacity is wasted during “lean periods”

Packet multiplexing

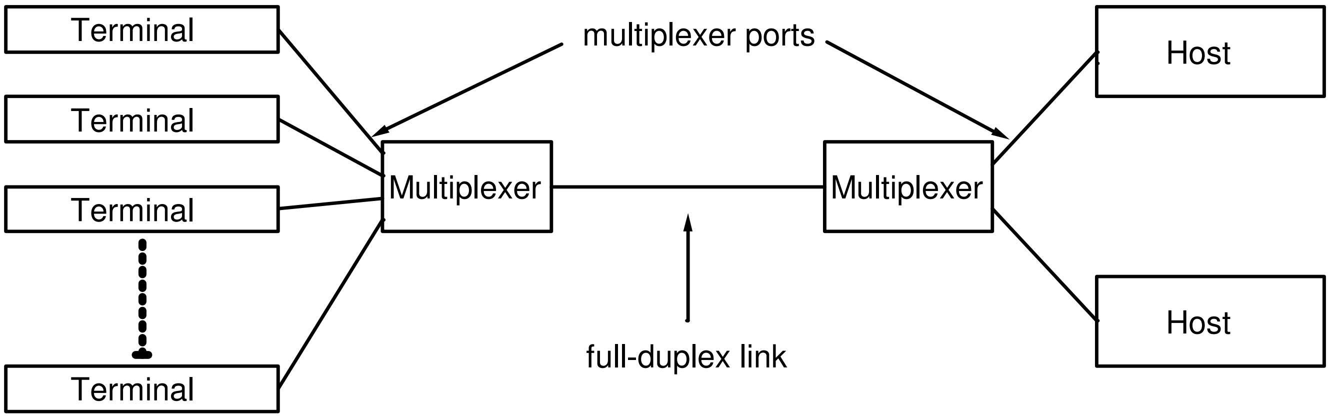


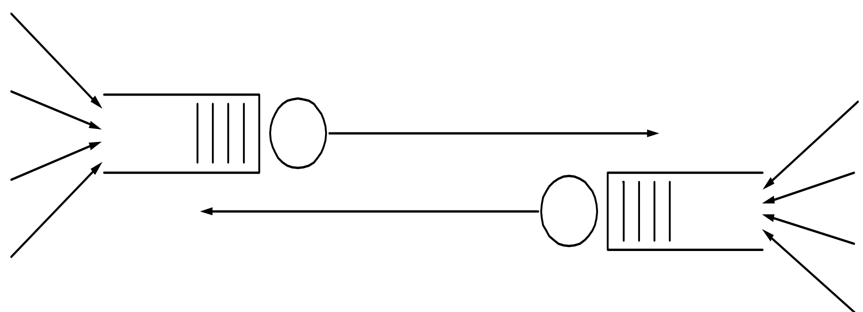
- *No partitioning* of the bit pipe
  - Apply entire bit rate to a source and hence, each packet gets the entire bit pipe for shorter periods of time
- Packets will need to contain header and trailer information to *identify* with a specific information flow (source, destination, application, etc.)

Packet multiplexing (contd.)

- Source peak rate can exceed link rate
  - Packets may need to be queued;
  - If buffer capacity is not sufficient, packets may be dropped and hence lost
- Abstraction:
  - Link is a server serving customers waiting in a queue
- Performance measures:
  - Packet delay
  - loss characteristics

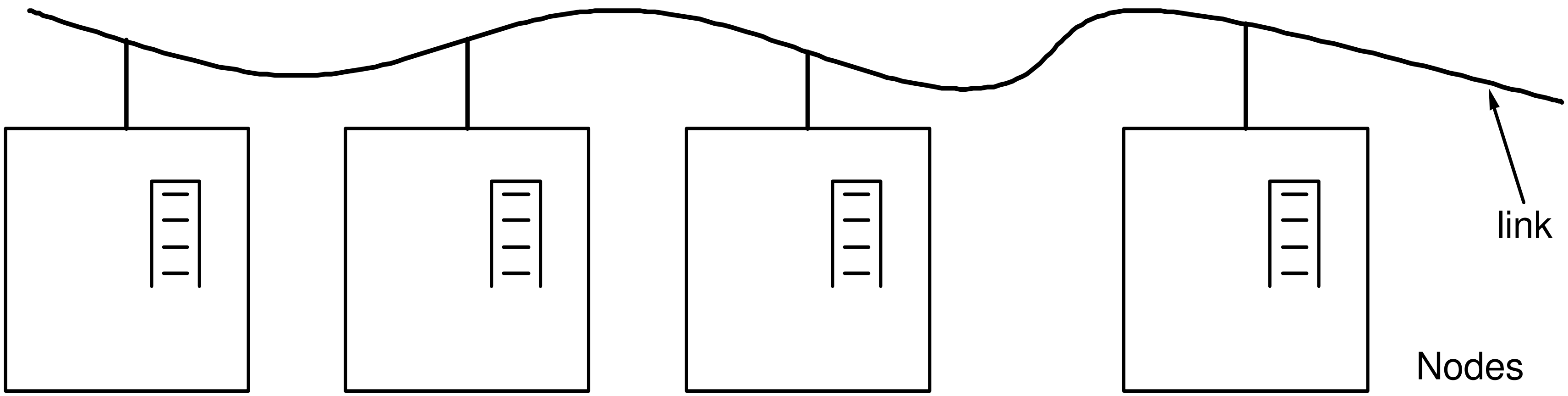
Centralized packet multiplexing





- Centralized packet multiplexing: multiplexers have full control over link’s transmission rate
  - Multiplexer stuffs packets on to link; has complete control over link
  - Scheduler can decide sequence of transmissions

Distributed packet multiplexing



- Distributed packet multiplexing: sources share link in a distributed fashion
  - Sources (*hosts/nodes*) connected to a multipoint link (wiretap, wireless channel).

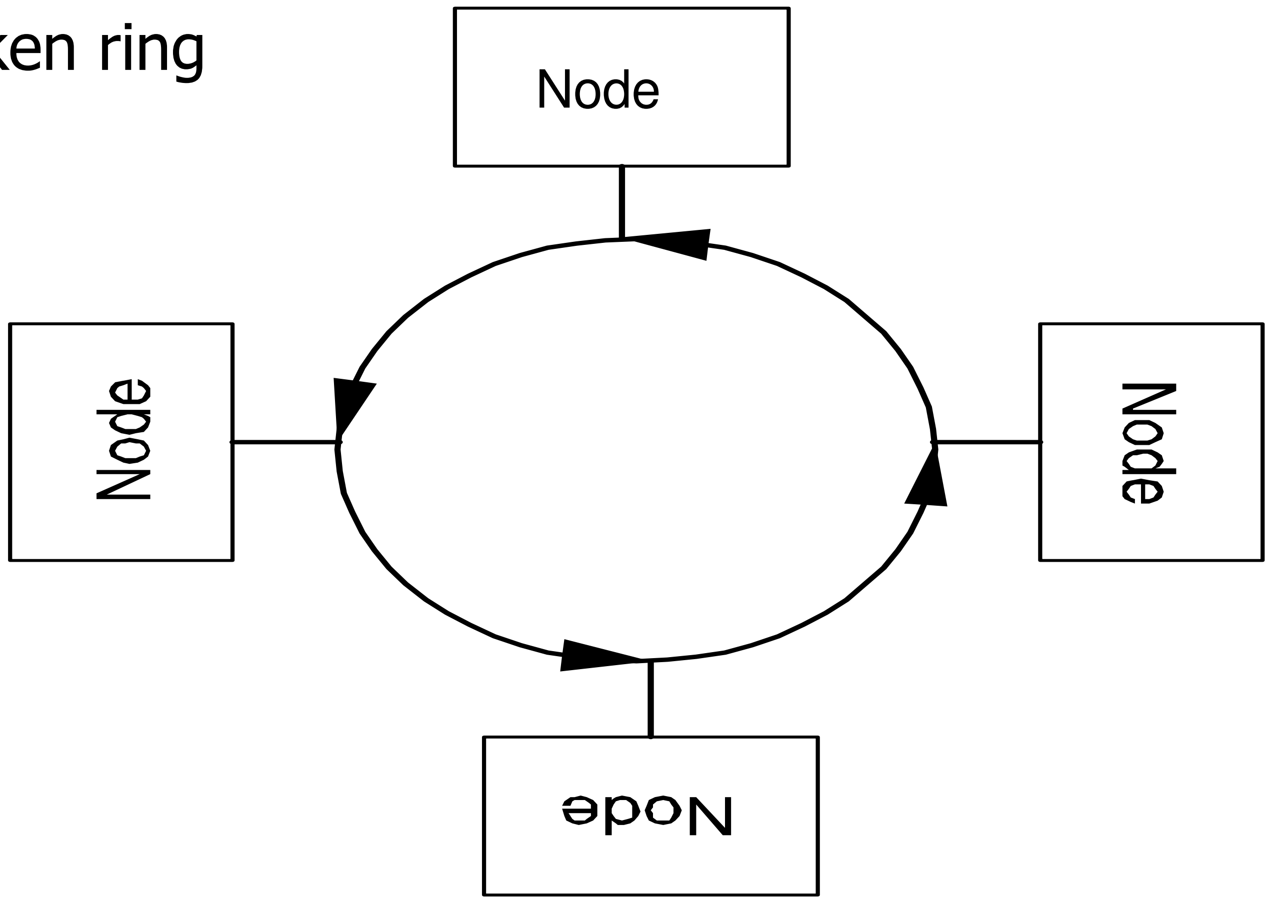
Distributed packet multiplexing (contd.)

- Only one source can successfully transmit on the channel at any time—*multiple access channel*

- Design Issue: Coordination among the sources
  - Random access: collision recognition and resolution
  - Controlled access: various flavors of polling — central or distributed

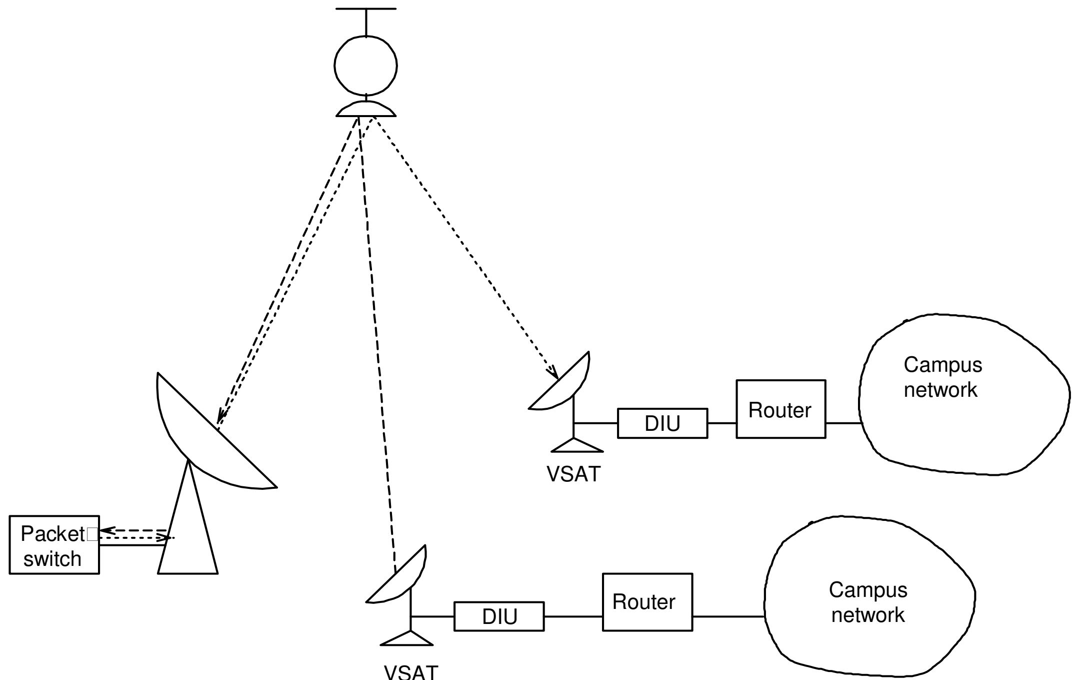
Polling based multiplexing

- Token ring



Reservation based multiplexing

- A Satellite System Example: very small aperture terminal (VSAT) Network

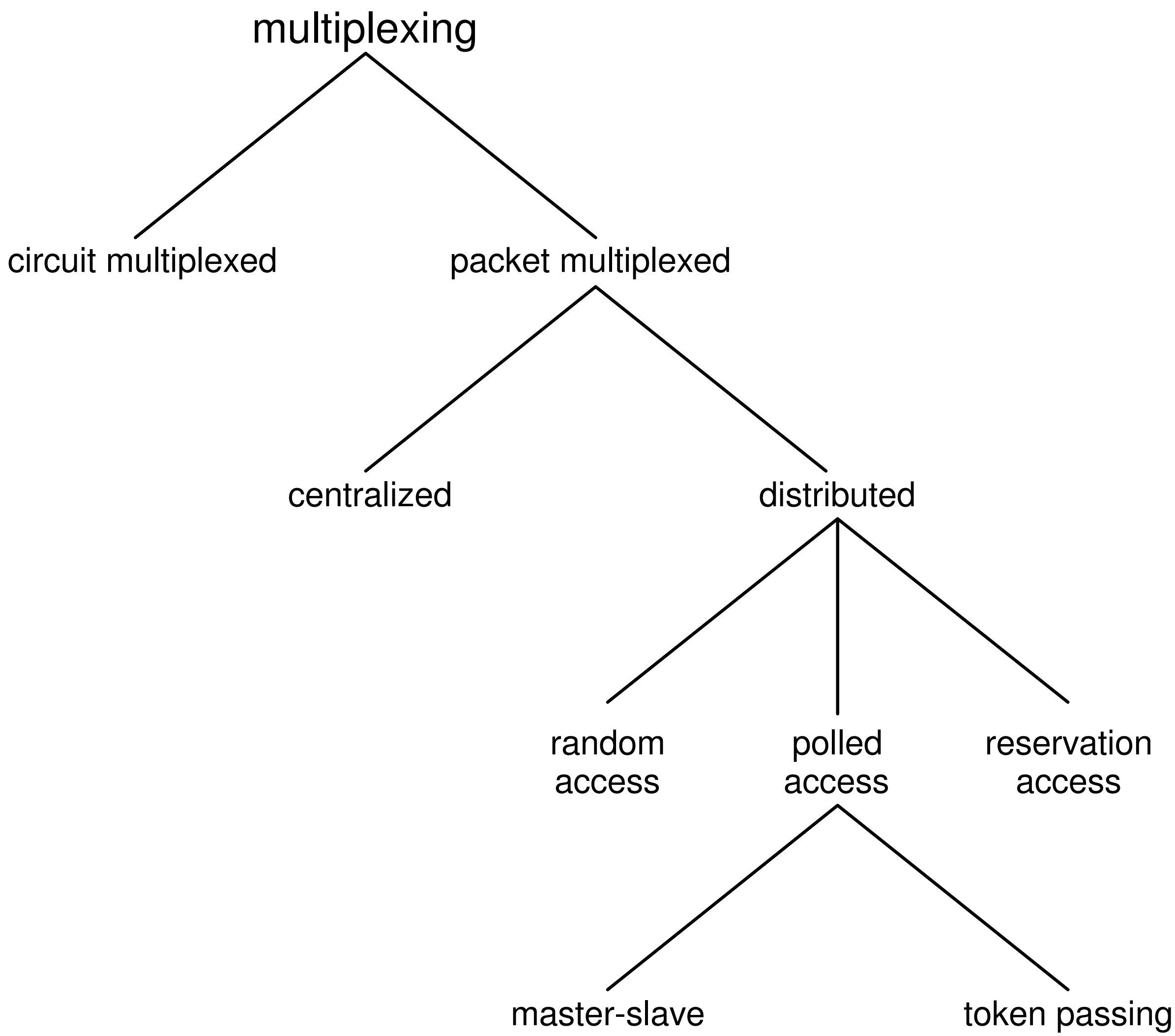


- Inbound channel to the hub is shared
- Propagation delay is large, no instantaneous feedback of result of the transmission — cannot use polling or contention based random access

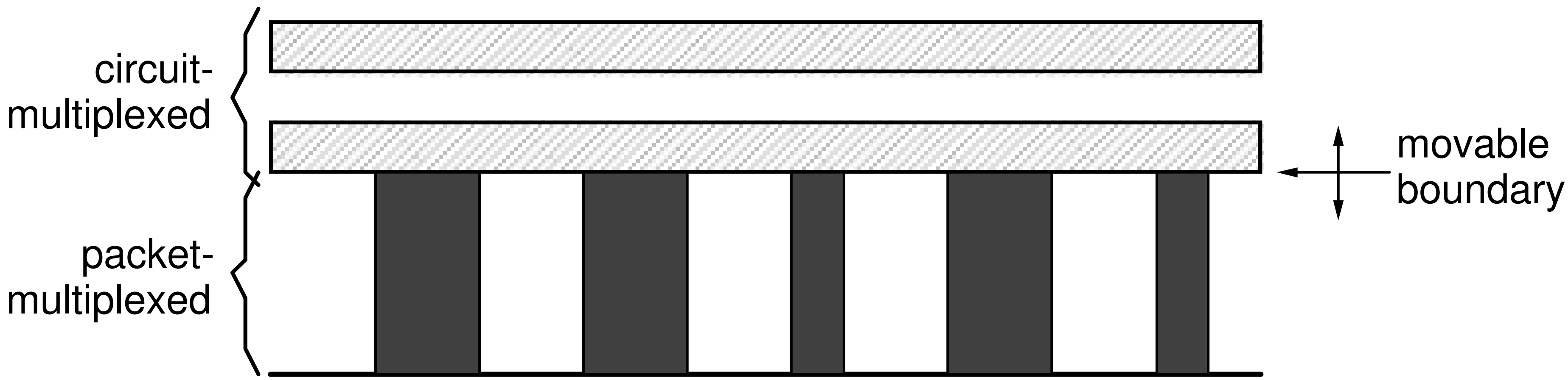
VSAT network (contd.)

- Ask for reservations from the hub using some contention mechanism
- Successful reservations and the frame structures are communicated on the outbound channel to the users

Multiplexing summary



Hybrid multiplexing



- Combining circuit multiplexing and packet multiplexing on a link; Partition capacity into circuit & packet multiplexing parts
- Important example: “2B+D” ISDN services
- More complex solutions vary boundary; rarely implemented

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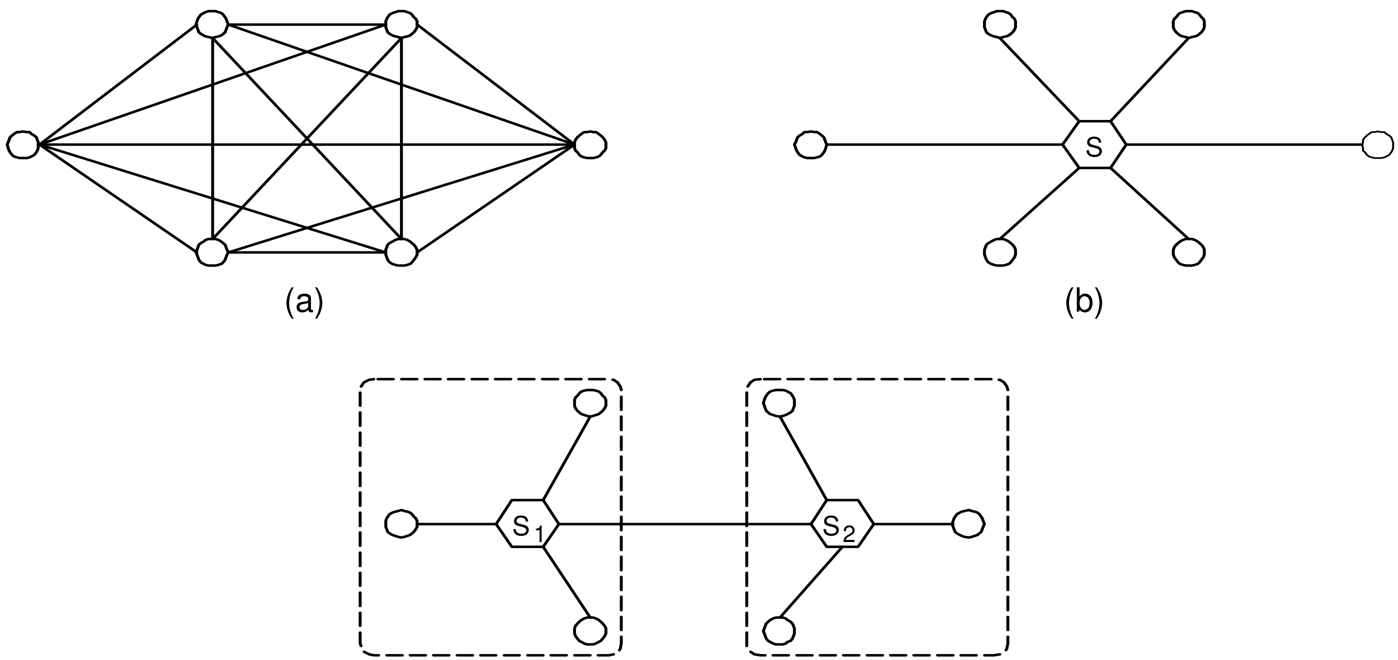
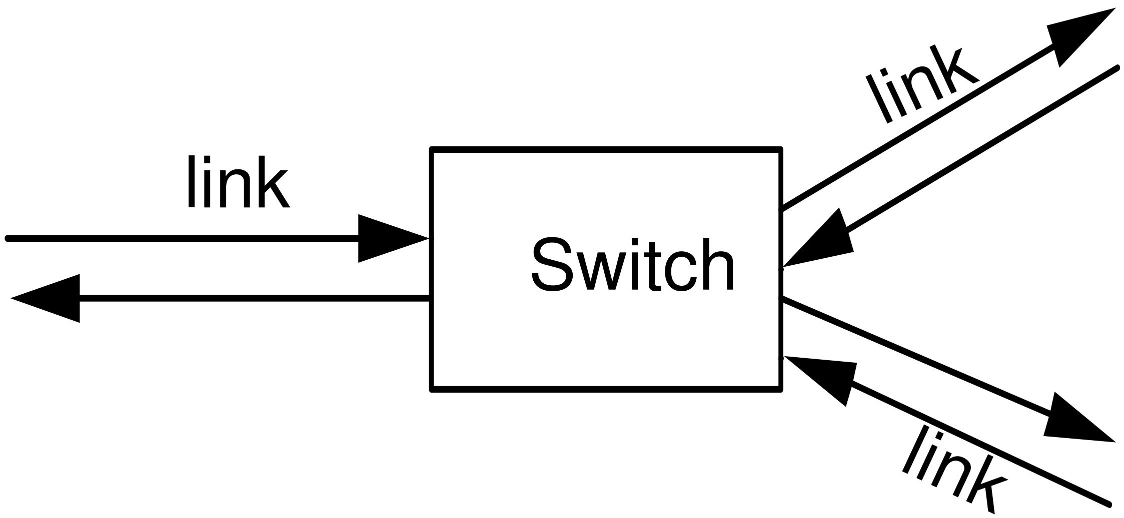
Switching: motivation



(a) (b) (c)

- A six node network constructed in three ways—(a) A brute force way. (b) Every node is connected to a central switch that selectively establishes paths between nodes and (c) Hierarchical network with inter-switch links with possibly multiplexing on it.

Switching



- Information flow will traverse more than one link.
- Switch is required at junction of two or more links.
- Switch is a device that *selectively establishes and releases connections* between communication links to allow sharing of these links among a number of flows (connections).

Switching (contd.)

- Switch moves information from link to link by *demultiplexing* on the inbound link and *multiplexing* on the selected outbound link.
- A switch is required with circuit multiplexing and centralised packet multiplexing

Functions of a switch

- Two categories, also called *planes* of functions—data plane and control plane
- Data plane functions
  - *Demultiplex* the flow (e.g., packet or time slot) on the input link
  - *Switch* the flow element onto the appropriate output link
  - *Multiplex* the flows on the output link

  - This implies every packet or slot in a TDM frame needs to be processed
  - Thus these are *fast timescale* functions: performed per packet or per frame
    - Specialized hardware may be used for these high speed functions

Functions of a switch

- Control plane functions
  - Connection setup and resource allocation/reservation
    - Achieved through source-network and switch-switch signaling
    - Functions performed over connection (flow) arrival timescales
    - General purpose processors can be used; Increasing interest in parallelization
  - Routing and local conditions information dissemination
    - Usually performed at timescales at which traffic characteristics change

Design issues in a packet switch

- Control and signaling functions include
  - populating the routing table
  - participating in distributed algorithms associated, for example, with routing
- Datagram packet switches:
  - every packet of a flow is treated independent of previous packets in the flow: queueing, address lookup, packet classification, etc.

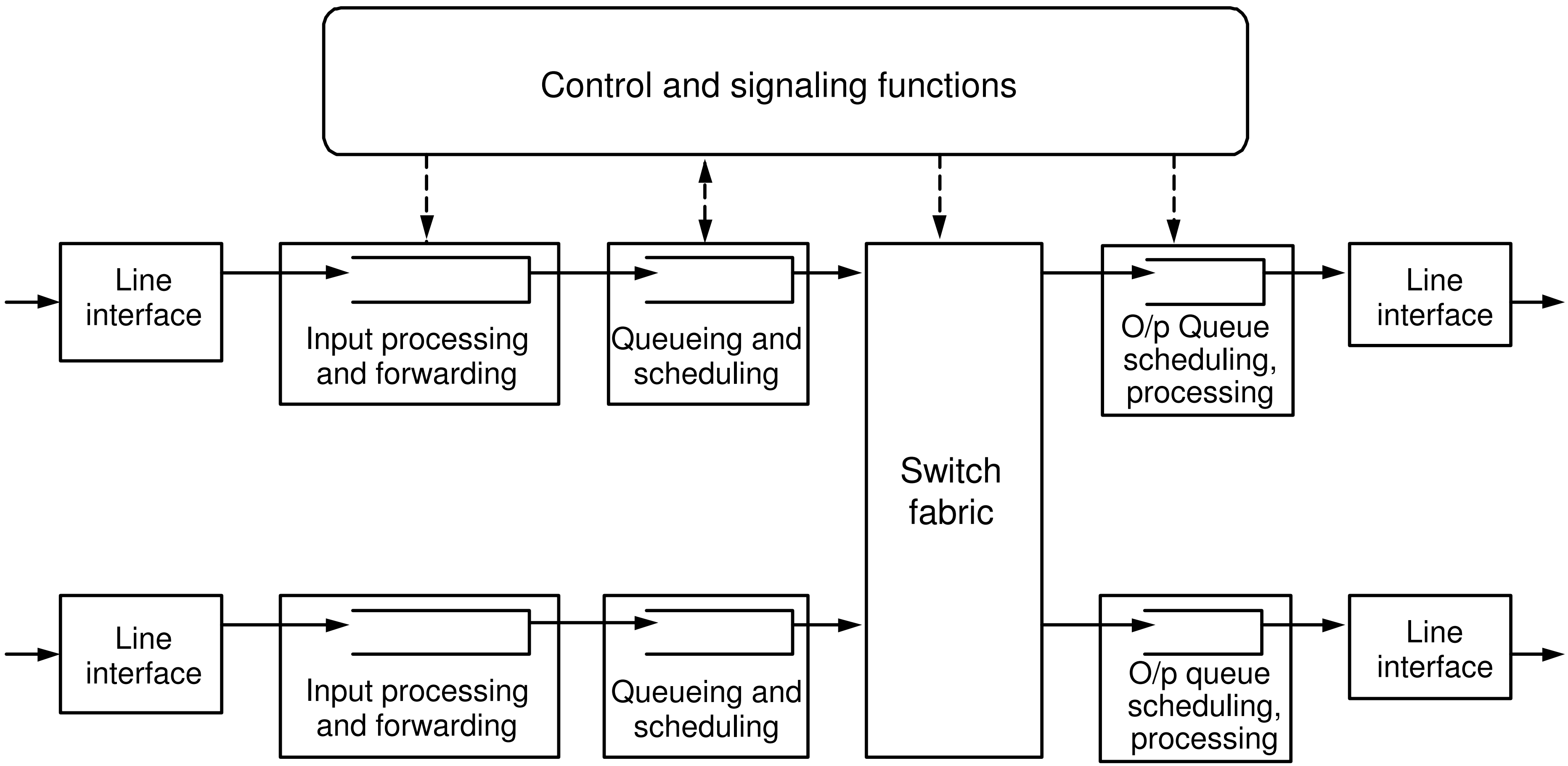
Virtual circuit packets switches:

  - Connection setup to allocate path and resources on links on path to the flow
  - Packets are assigned link level labels, and switched based on labels
  - Performance measures: switching delay in getting to the output queue, packet loss rate

Design issues (contd.)

- Input and output lines could be slotted or unslotted
  - Correspondingly, packets lengths and interarrival time have discrete or continuous distributions
- Packet lengths could be fixed or variable

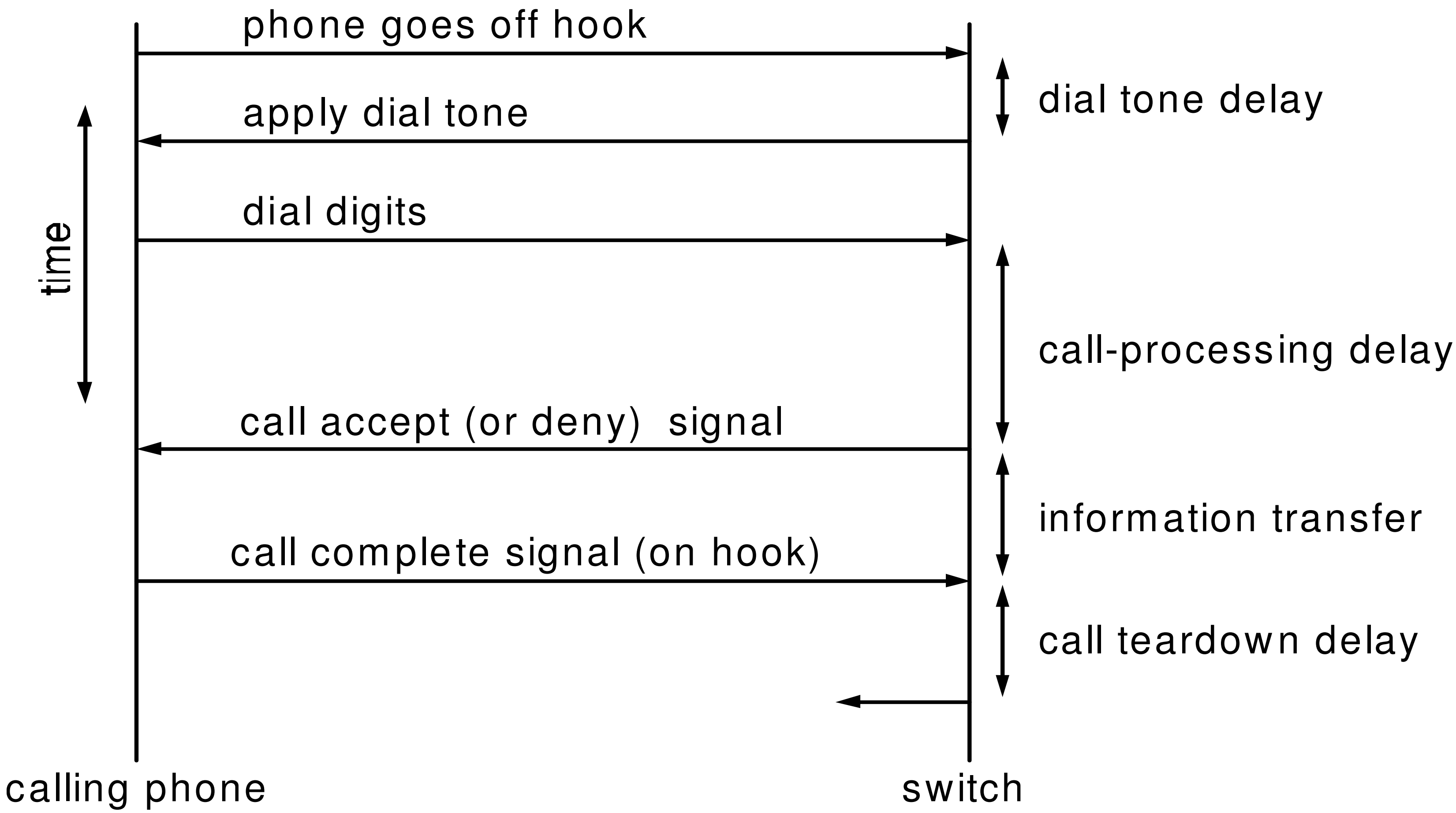
Components of a packet switch



Call setup in a circuit switch

- Detect off hook, apply dial tone, accept digits, perform digit analysis
- From routing algorithm determine next switch on path to destination and perform signaling to reserve channel on link to the switch
- If path is available reserve resources and “program” the pair “output port:TDM slot” for the channel on the incoming port of the call
- Maintain call
- Release resources on completing the call and perform possible billing functions

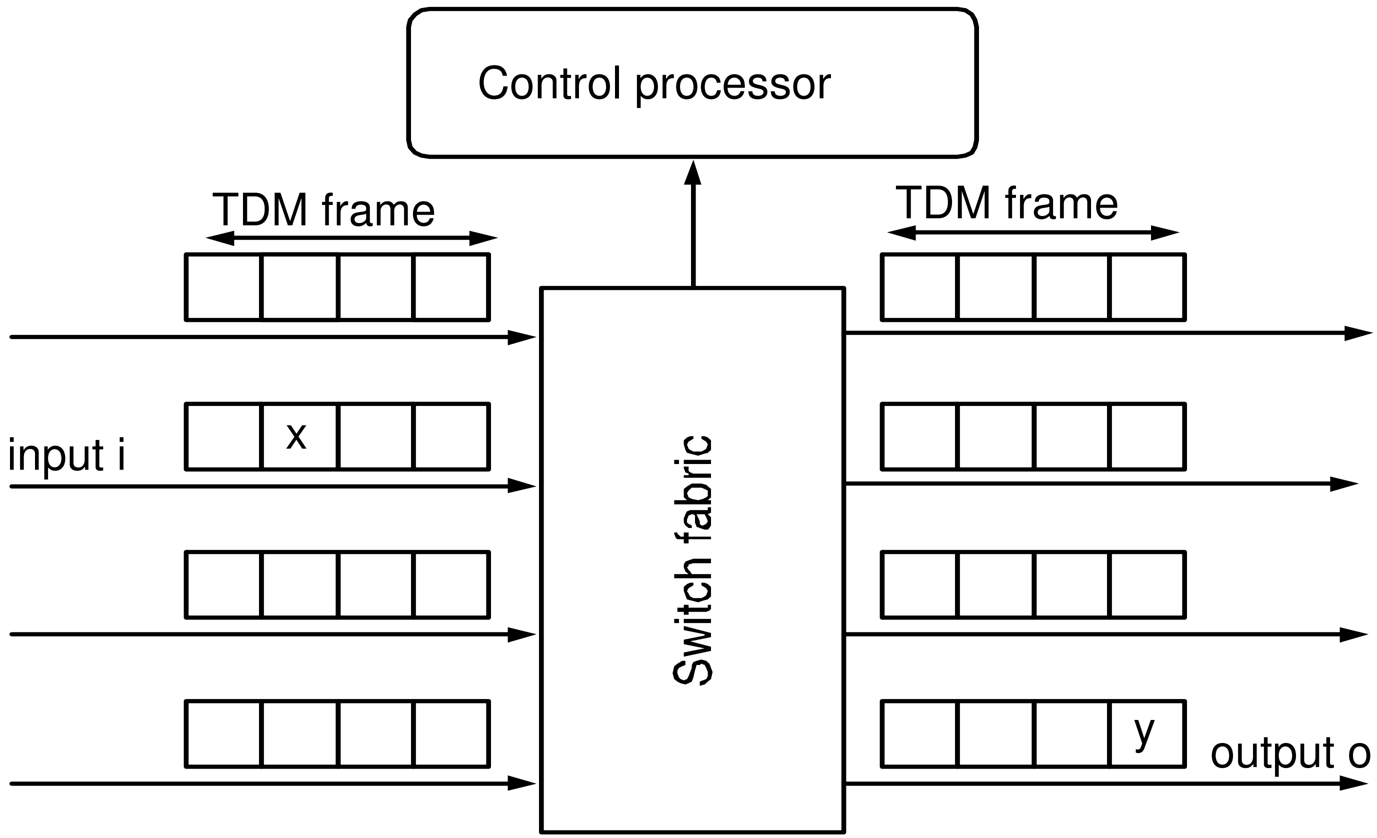
Call setup (contd.)



Functions of a circuit switch

- *Switching* functions such as
  - setting up circuit inside switch between input and output and maintain it for duration of call
- *Call processing* functions such as
  - off-hook detection
  - digit acceptance and analysis
  - routing call and corresponding signaling for path reservation and billing functions
- *Background* functions for executing protocols for routing, management and maintenance of the switch

Circuit Switch: Logical View



Operation of a circuit switch

- Each slot on each input line contains the information flow unit for a circuit
- At the time of circuit set up, the switching pattern—output port and the slot in the output port, is determined
- The fabric will perform the switching operation which is repeated in every frame
- In figure, the contents of slot S on input line i are switched to slot S_o on line o

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Routing

- A *route* is an ordered sequence of links between a source and a destination

- A network node, or a switch, performs the routing function along with multiplexing and switching;

  Nonetheless, routing is a “network wide” function and the nodes collaborate in making routing decisions

Routing (contd.)

- Often, routing and forwarding are used synonymously and this is wrong!
  - An incoming packet is processed, its output port determined and then the packet is forwarded to the output link. Thus *forwarding* is a fast timescale operation and is a data plane function, meaning it operates on the data.
  - The decision of which output port this packet should be sent is made on slower timescale. This depends on the route that the packet will take in the network. Thus this is a *control plane activity*.
  - The forwarding function consults a *routing table* to decide the output port for a packet. The *routing* function populates this routing table

Routing: computation models

- Objective of routing algorithm: use network resources efficiently
  - Conflicts of providing QoS to customers and utilizing network resources efficiently needs to be addressed
- Network topology information and user requirements need to be known
- Routing decisions can be centralized or distributed

Routing: computation models (contd.)

- In *centralized* routing the network topology information is collected using a distributed algorithm at a central node where the routes are determined for every possible source-destination pair. These routing decisions communicated to all the nodes in the network
- In *distributed* routing, distributed algorithms are used to collect topology information *and* make routing decisions
- Information aggregation may be used to minimize “information explosion”
  - An obvious solution is use of hierarchies.

Distributed routing

- Decision Models
  - Source Routing: The decision on the sequence of the links to the destination may be made at the source
    - The routing information is embedded into the packet and is used by the intermediate nodes in the network to forward the packet appropriately
  - Hop-by-Hop Routing: Each node only knows the ‘next node on the best route’ to the destination
    - The nodes need not know the entire route to the destinations

Tasks in routing

- Exchange of local topology information with neighbors at faster timescales
  - This helps keep track of link status and also the demands on the links. The latter helps in determining QoS capabilities of the routes.
- Perform any aggregation that may be required by the algorithms and disseminate aggregated information.
- A Routing Protocol will be used to exchange information that is necessary for the routing algorithm

Tasks in routing (contd.)

- Route computations are based on the topology information collected and use a *routing algorithm*.
- Topology information exchange always occurs. Route computation may be triggered and/or time driven.
- Granularity of route computation
  - Fine grained *on demand routing* on a per session basis
  - Coarse grained *per flow* routing where *fat pipes* are a priori set up

Design and performance issues

- Routing protocols:
  - What information to exchange, how often, how to exchange
- Routing Algorithms:
  - Objective functions for best effort routing and QoS routing
- Emerging scenarios
  - Multicast routing algorithms
  - Routing protocols and algorithms for rapidly changing topologies, e.g., ad hoc networks

Design and performance issues (contd.)

- Performance measures:
  - Connection blocking probability, load imposed on the network, adaptation to changes in the network conditions.

  - Connection blocking only relevant in connection based networks. Typically associated with circuit multiplexed networks.
    - In *datagram* networks, connections are not set up. Hence no concept of connection blocking.
    - *Virtual circuit* based networks use packet multiplexing but set up a connection before data transfer begins to alert the switches of the creation of a flow

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Network management

- Handle conditions for which the network is not engineered
  - Different from ‘congestion control’ where the overload conditions are short lived.
- All operational networks define a management architecture to collect and control the network resources.
- Performance data are collected by *managed* network devices these are in turn are gathered by a *network management* station in the network that will analyze the data that has been collected.

Network management (contd.)

- The management architecture provides some *control functions* that can be performed on remote managed devices by management stations either in a programmed manner or through an operator
- Security issues are also handled by a network management architecture.

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Traffic controls and timescales

- Network functions cover a wide variety of timescales—of the order of a few microseconds to minutes to months and years. Rather than consider absolute time we identify the following four relative timescales:
  - Packet timescale (packet transmission time; seconds or milliseconds)
  - Session, call or flow timescale (typically minutes)
  - Busy hour or traffic variation timescale (typically hours)
  - Provisioning timescale (usually hours to days or weeks)

Traffic controls and timescales (contd.)

- Packet timescale controls discriminate between treatment of individual packets (e.g., transmission scheduling, buffer allocation)
- Accepting and the routing of a call in connection oriented networks are made on slower timescales, and in the order of session interarrival times
- Since traffic processes vary over a day/week and probably have some cyclical patterns, resource allocation algorithms and thresholds may need to change at the rate at which traffic processes in the network change.
- Resource provisioning occurs over longer periods, e.g., from months to years