Outline

1. Introduction and Overview

- Switching and Transmission
- Multiplexing and Concentration
- Timescales of Information Transfer

2. Circuit Switch Design Principles

- Space-domain Circuit Switching
  - i. Nonblocking Properties, Complexity
  - ii. Clos, Benes and Cantor Switches
- Time-domain Switching

3. Fundamental Principles of Packet Switch Design

- Packet Contention
- Interconnection Networks (Banyan Networks)
- Sorting Networks
- Nonblocking and Self-Routing Properties of Clos Networks

Outline

4. Advanced Packet Switching Principles

- Performances of Simple Switches
- Look-Ahead Contention Resolution
- Speedup Principle
- Channel-Grouping Principle
- Knockout Principle
- Replication Principle
- Dilation Principle

5. Advanced Switch Design Principles

- Switch Design Principles Based on Deflection Routing
  i. Tandem-Banyan Network
  ii. Shuffle-Exchange Network
  iii. Feedback Shuffle-Exchange Network
  iv. Feedback Bidirectional Shuffle-Exchange Network
  v. Dual Shuffle-Exchange Network
- Switching by Memory I/O

Outline

6. Switching Principles for Multicast, Multirate, and Multimedia Services

- Multicast Switching
  - i. Multicasting Based on Nonblocking Copy Networks
  - ii. Performance Improvement of Copy Networks
  - iii. Multicasting Algorithm for Arbitrary Network Topologies
  - iv. Nonblocking Copy Networks Based on Broadcast Clos Networks
- Path Switching
  - i. Basic Concept of Path Switching
  - ii. Capacity and Route Assignments for Multirate Traffic
  - iii. Trade-Off Between Performance and Complexity
  - iv. Multicasting in Path Switching

Outline

7. Packet Switching and Information Transmission

- o Duality of Switching and Transmission
- o Parallel Characteristics of Contention and Noise
  - i. Pseudo Signal-to-Noise Ratio of Packet Switch
  - ii. Clos Network with Random Routing as a Noisy Channel
- o Clos Network with Deflection Routing
  - i. Cascaded Clos Network
  - ii. Analysis of Deflection Clos Network
- o Route Assignments and Error-Correcting Codes
  - i. Complete Matching in Bipartite Graphs
  - ii. Graphical Codes
  - iii. Route Assignments of Benes Network
- o Clos Network as Noiseless Channel-Path Switch
  - i. Capacity Allocation
  - ii. Capacity Matrix Decomposition
- o Scheduling and Source Coding
  - i. Smoothness of Scheduling
  - ii. Comparison of Scheduling Algorithms
  - iii. Two-Dimensional Scheduling

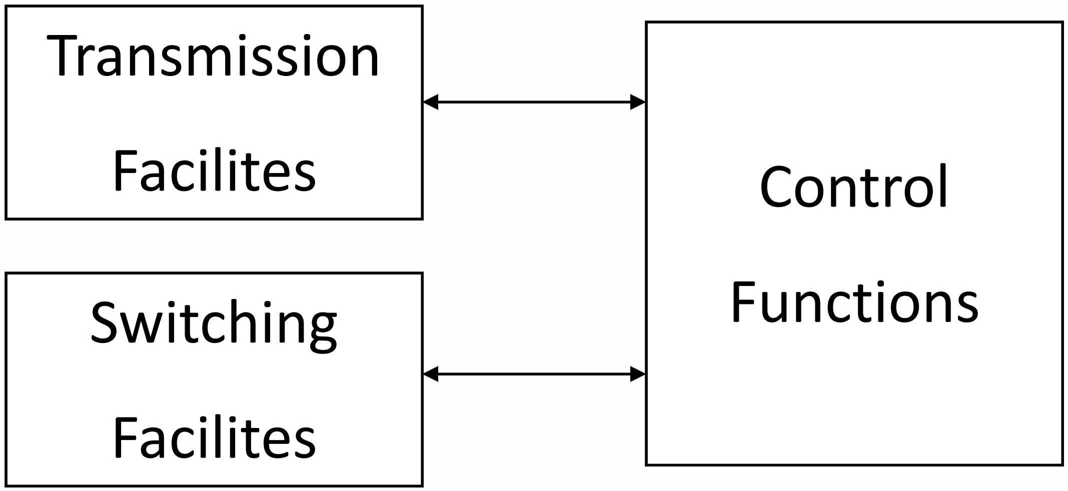
Roles of Switching and Transmission

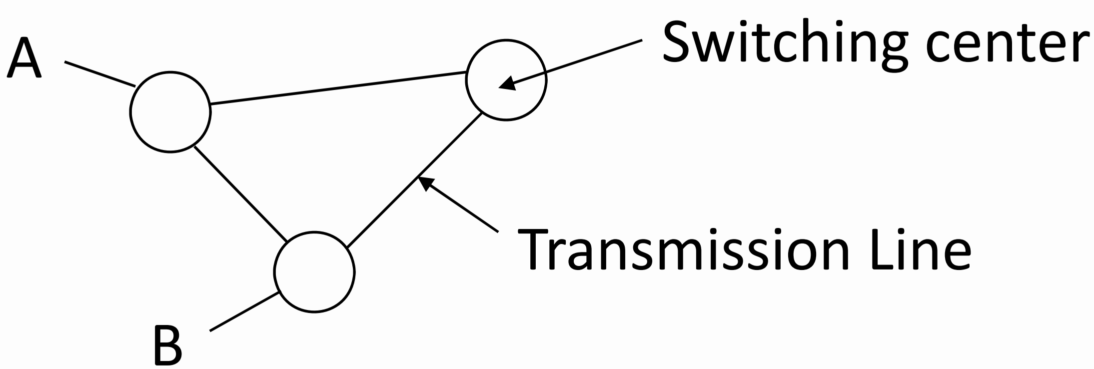
1. **Merging of computer and communications technologies**
2. **Traditional Computer Networks**
   - Services non real time
   - data rate not too high
   - service quality not guaranteed
3. **Telephone Networks**
   - Real time
   - low data rate (64 kbps)
   - Service quality guaranteed

Roles of Switching and Transmission

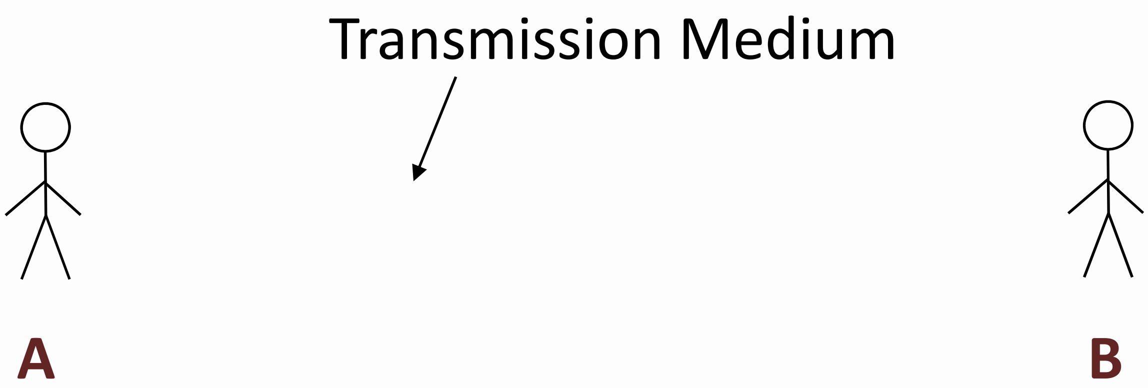
4. **Computer Networks on Telephone Networks**
   - Modems
   - leased line
5. **Multimedia services**
6. **Integrated Communications Networks**
7. **Broadband**
8. **Integration**
9. **Support of unforeseen services**

Roles of Switching and Transmission





Roles of Switching and Transmission

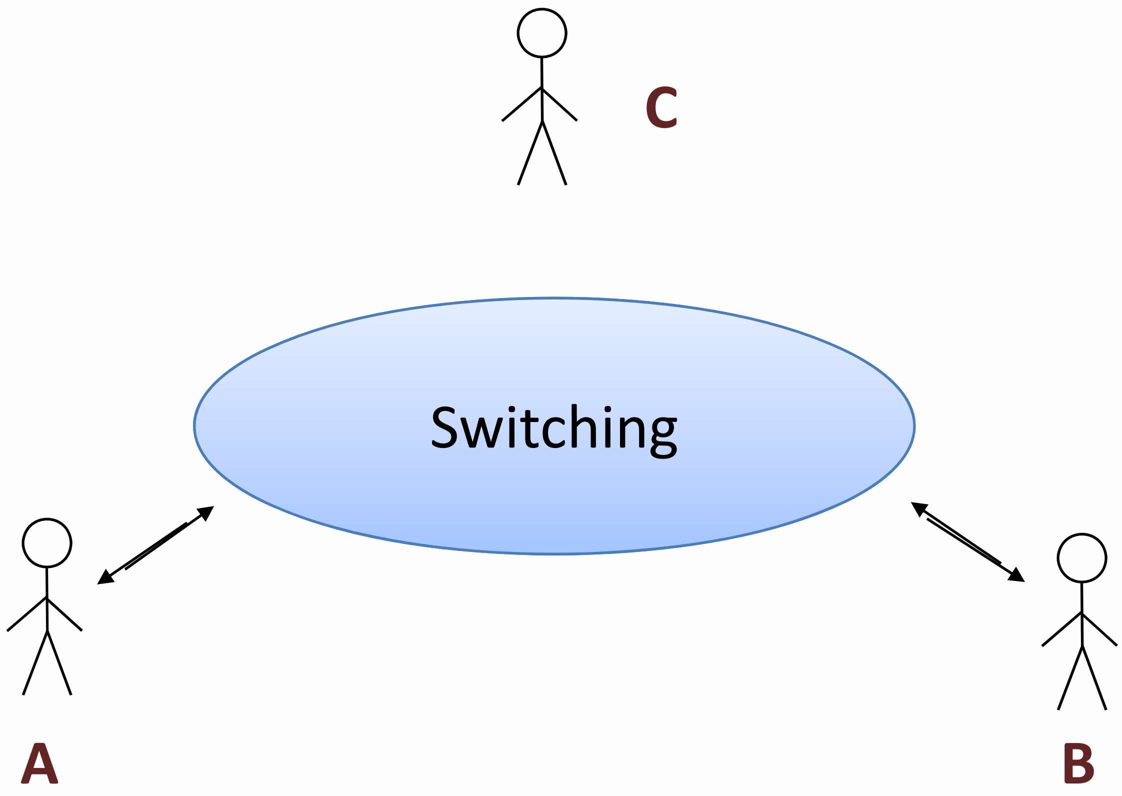


When there are only two users, information from A is by default destined for B, and vice versa

For a two-user network, switching is not required

Fig. 1.1. A two-user network; switching is not required

Roles of Switching and Transmission

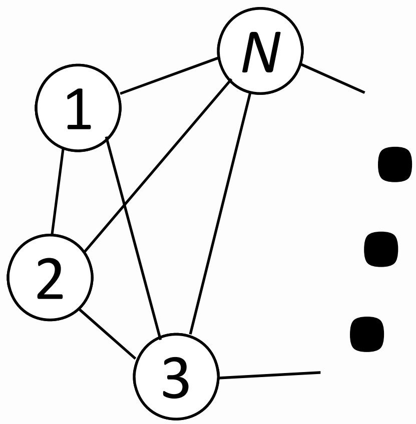


Information from A may be destined for B or C

For a three-user network, switching is required

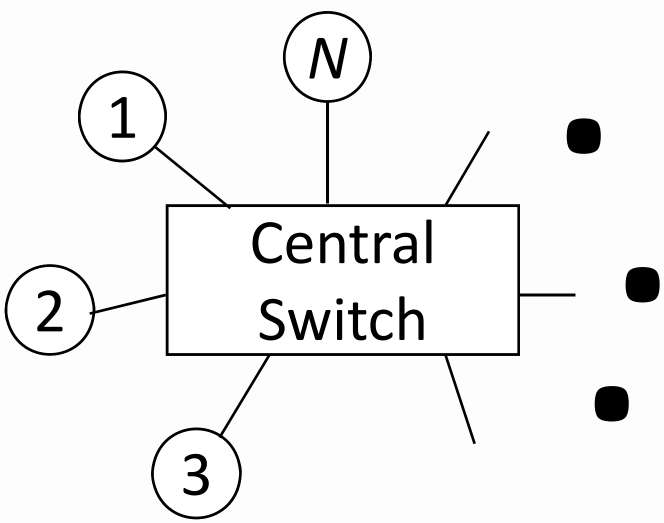
Fig. 1.2. A three-user network; switching is required

Roles of Switching and Transmission



Switching is performed at user's location by selecting one of the links for reception

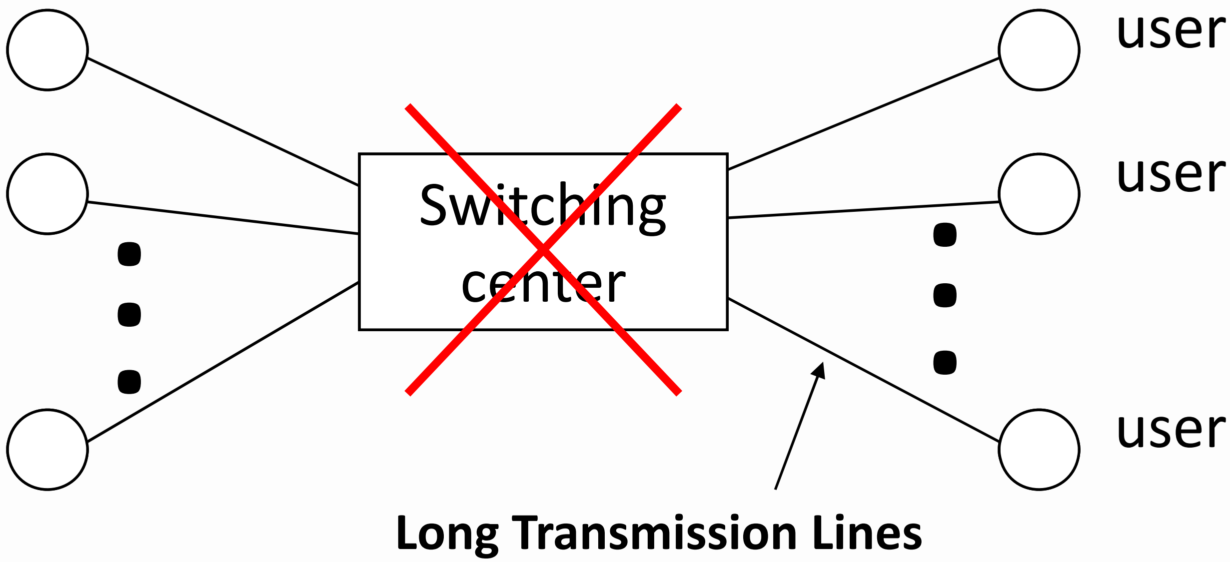
\# of bi-directional links = $N(N-1)/2$



Switching is performed by a central switch

Fig. 1.3. N-user networks with switching performed (a) at users' location (b) by a central switch

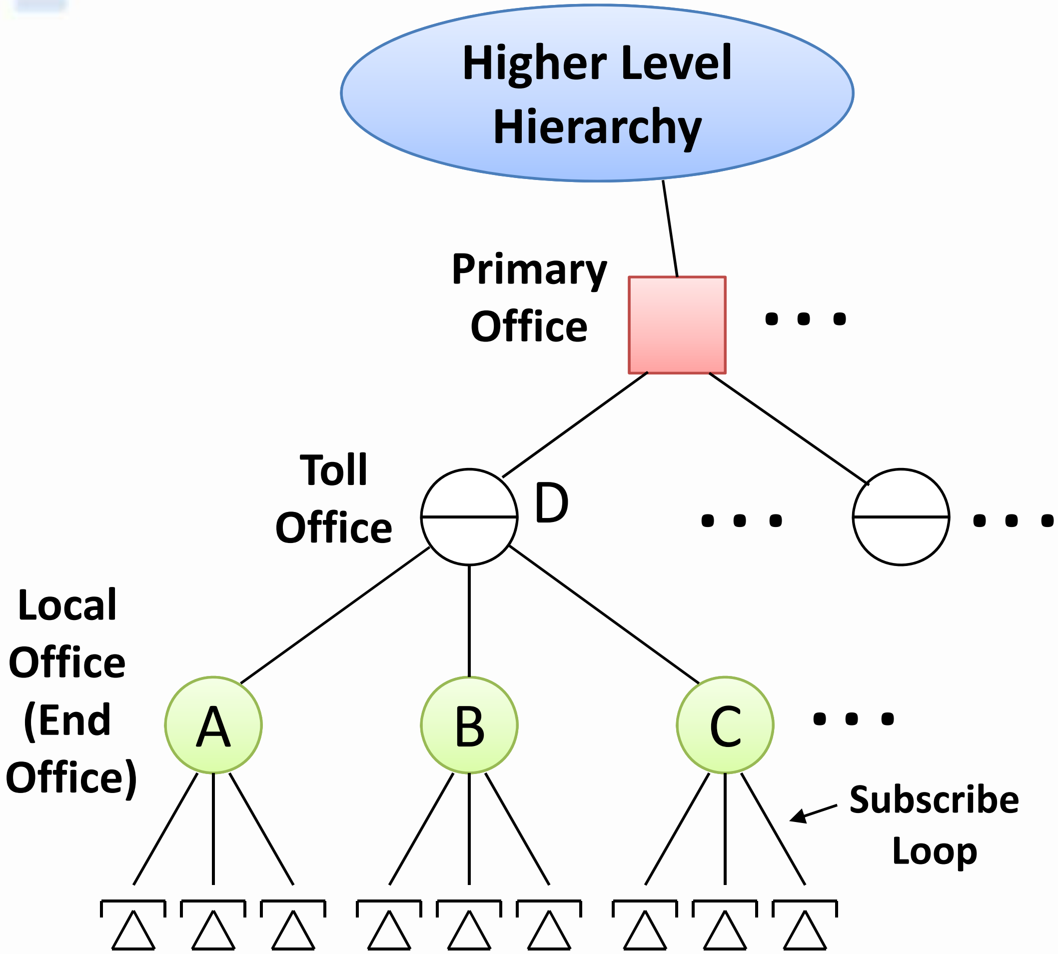
Roles of Switching and Transmission



In case the totally centralized switch is not attractive, no communication can be processed between any users

An example in which totally centralized switching is not attractive

Transmission Hierarchy



i.) Decrease of Traffic volume as going up in hierarchy

ii.) Resources at upper hierarchy shared by larger population

iii.) Hierarchical routing

Fig. 1.4. Telephone network hierarchy

Multiplexing and Concentration

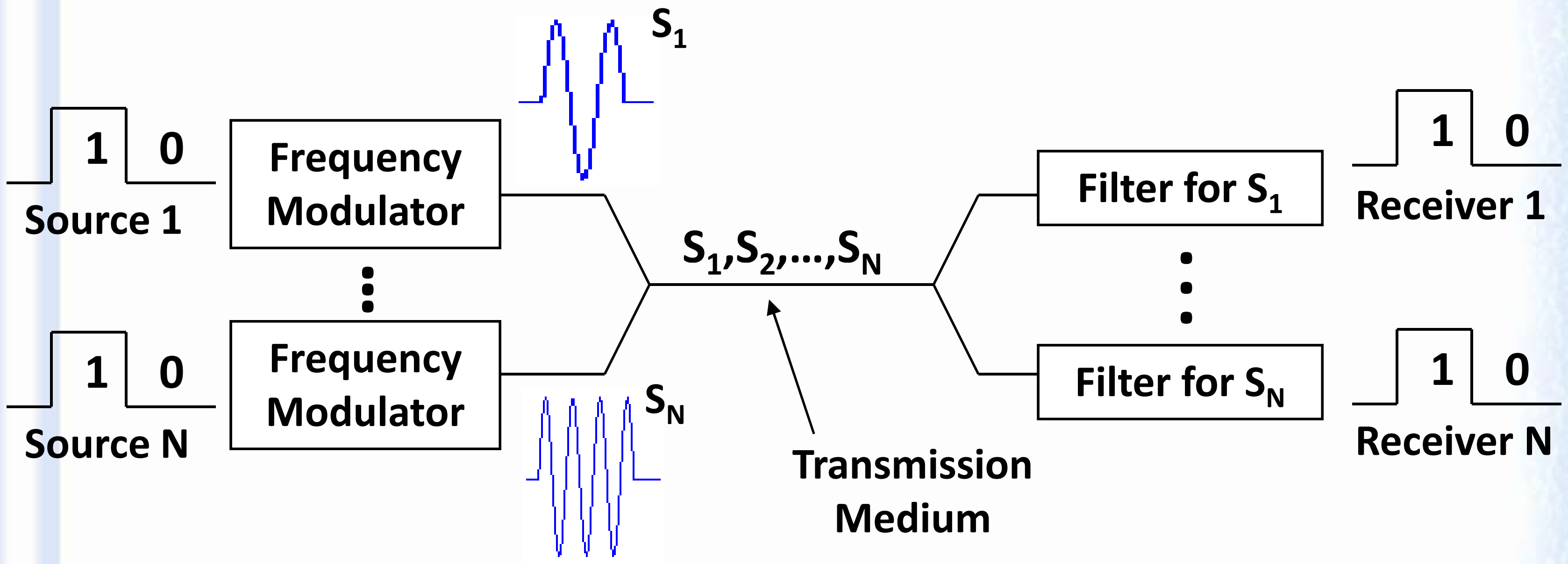


Fig. 1.5. Frequency-division multiplexing

Multiplexing and Concentration

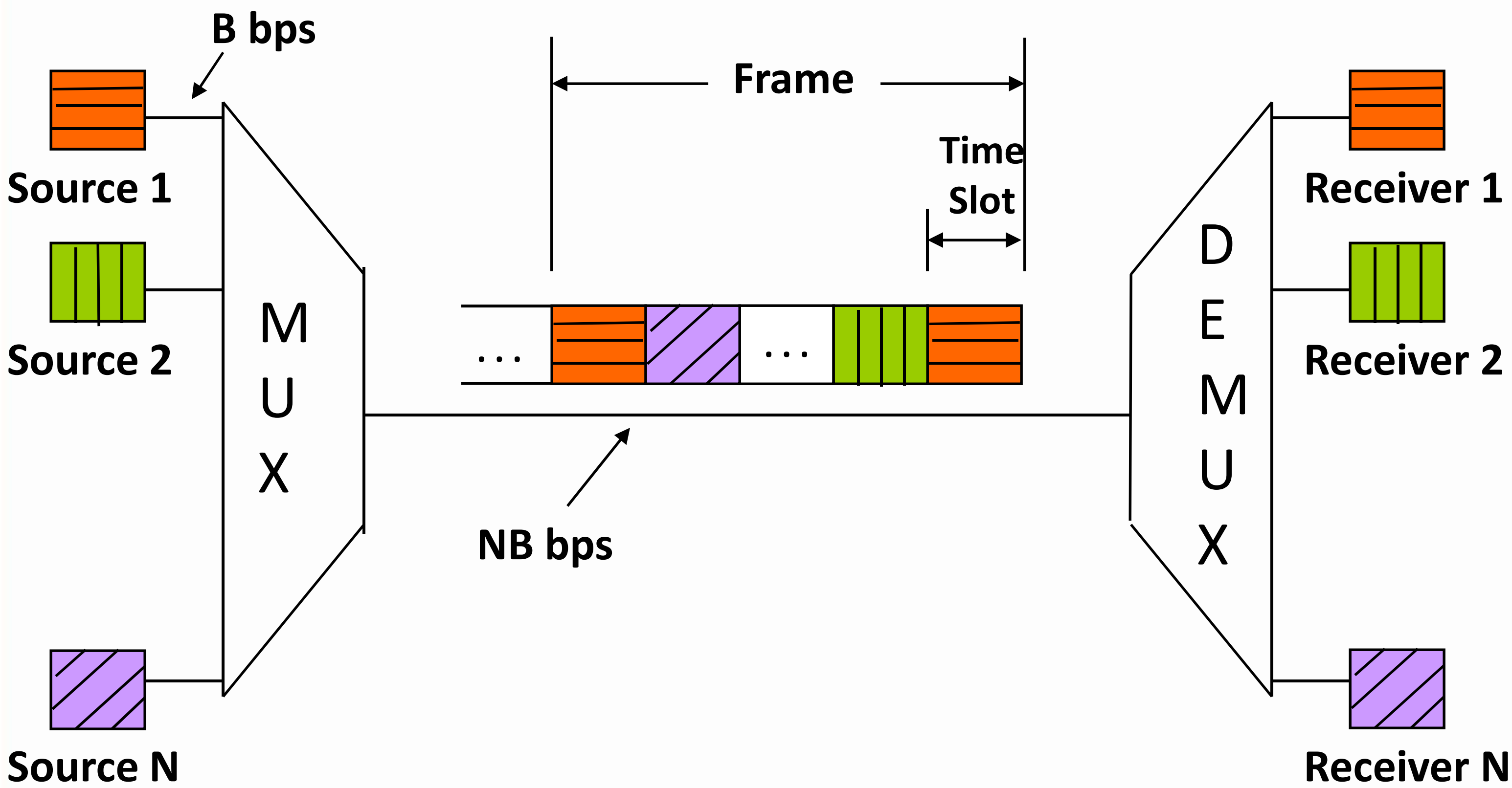
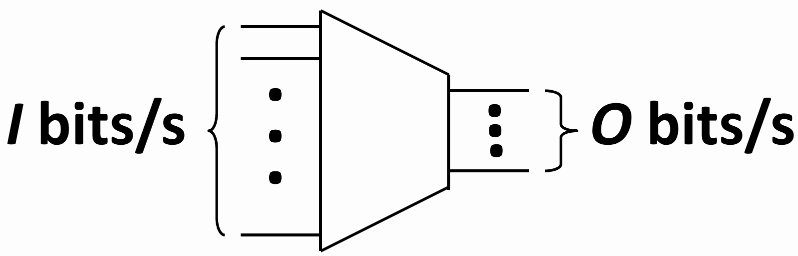


Fig. 1.6. Time-division multiplexing

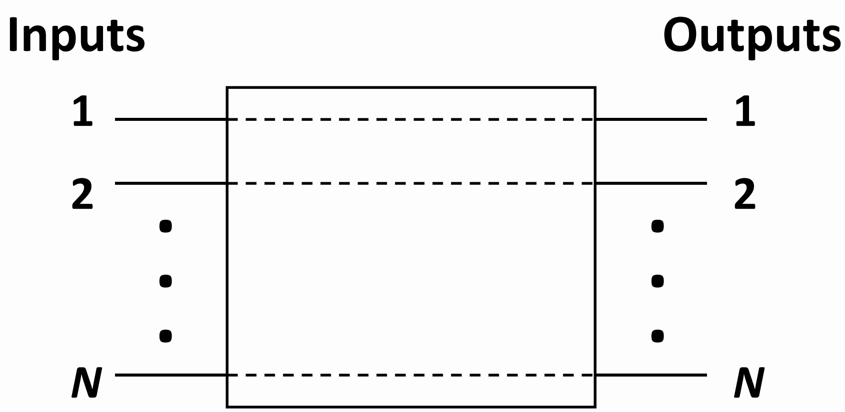
Multiplexing and Concentration

Difference between Multiplexing and concentration :



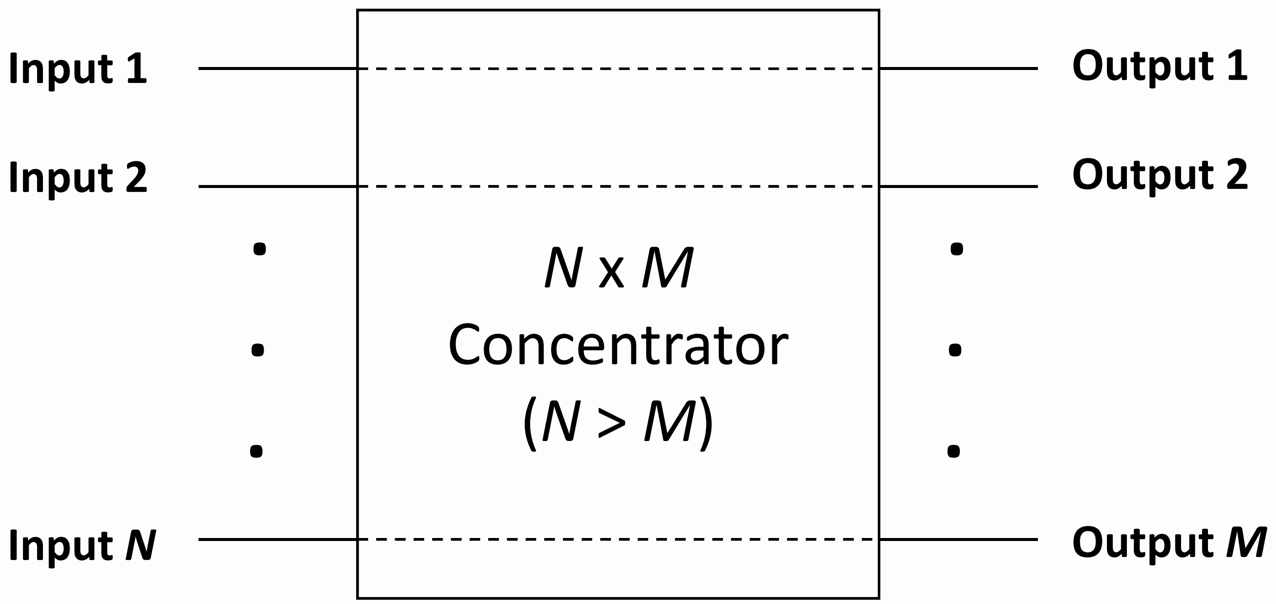
I = *O* in mux. system
I > *O* in concentrator

Difference between Multiplexing and Switching :



Connectivity is static in mux, system but dynamic in switching system

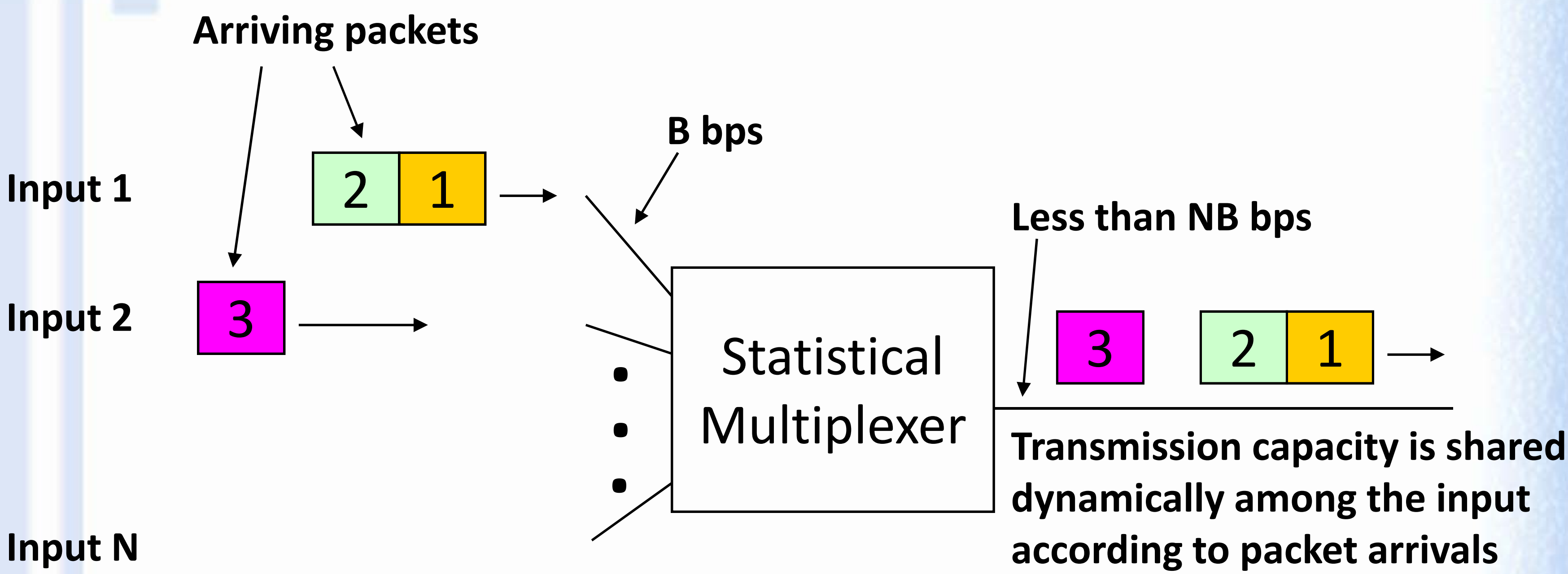
Multiplexing and Concentration



An active input is assigned to one of the outputs. It does not matter which output is assigned.

Fig. 1.7. An *N* x *M* concentrator

Multiplexing and Concentration



- Combines multiplexing and concentration
- Packet header indicating destination
- Switching involved
- Connectivity changes with time

Fig. 1.8. A Statistical multiplexer

Multiplexing and Concentration

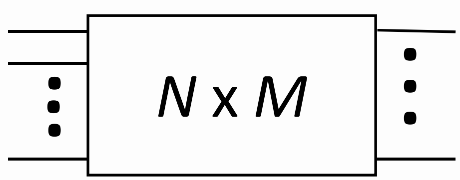
Sessions, circuits (concentration) :

- Session needs to be set up before communication
- Exclusive and non-exclusive dedication of resources during connection
- Virtual circuits (not connection oriented)

Messages (Statistical multiplexing) :

- variable packets
- talk spurts

TASI :



N > M

Satellite Links assigned based on talkspurts

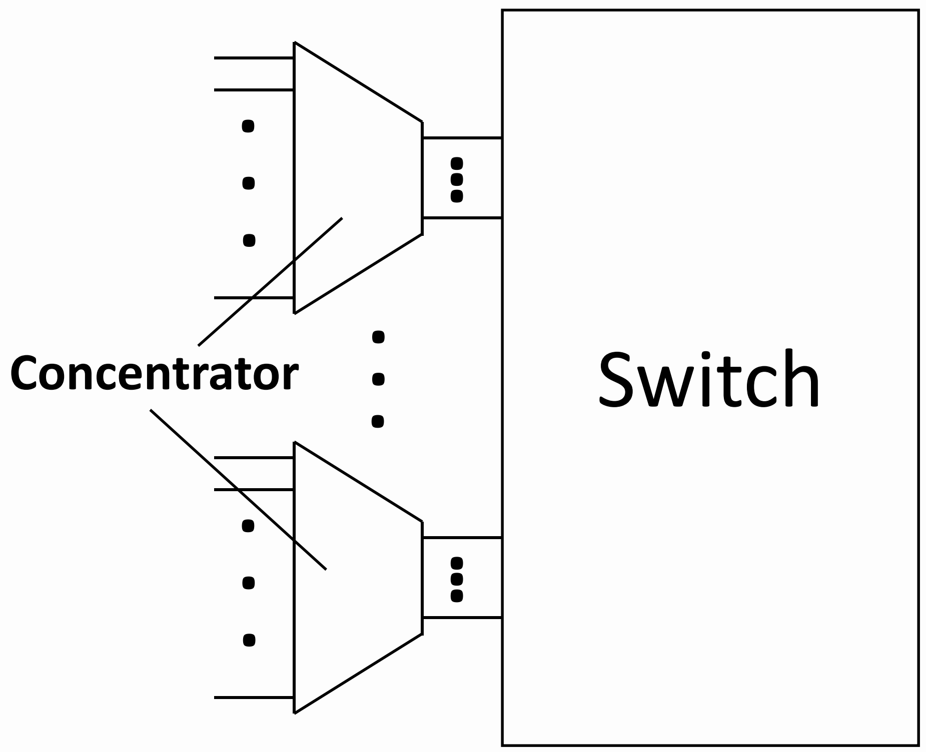
Timescales of Information Transfer

Packets and Cells :

- Transport Entities
- Variable versus fixed length
- Long versus short packets

Messages are broken into smaller packets in network since:

- Network does not support large packet size
- Most networks are store-and-forward network, less delay under light load
- Prevent a long packet from hogging a communication channel



Concentration used to reduce switching cost

Broadband Integrated Services Network

- Capable of supporting many different kinds of services
- Same resources can be assigned to different services at different times
- Better resources sharing (different services have different peak times)
- Support unforeseen future services

Challenge: How to support and control traffic of diverse characteristics in one single network?

Broadband Integrated Services Network

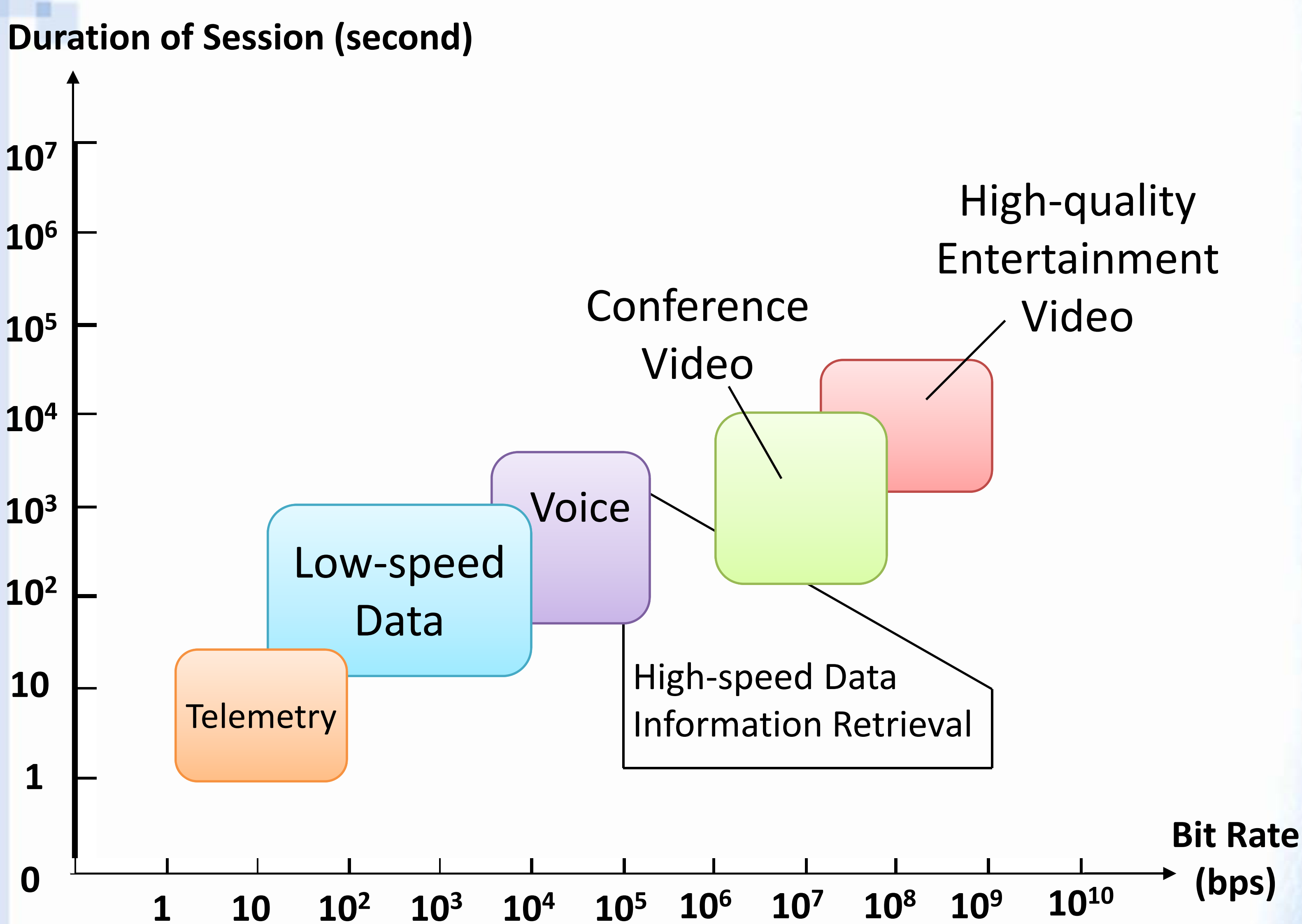


Fig. 1.9. Holding times and bit rates of various services

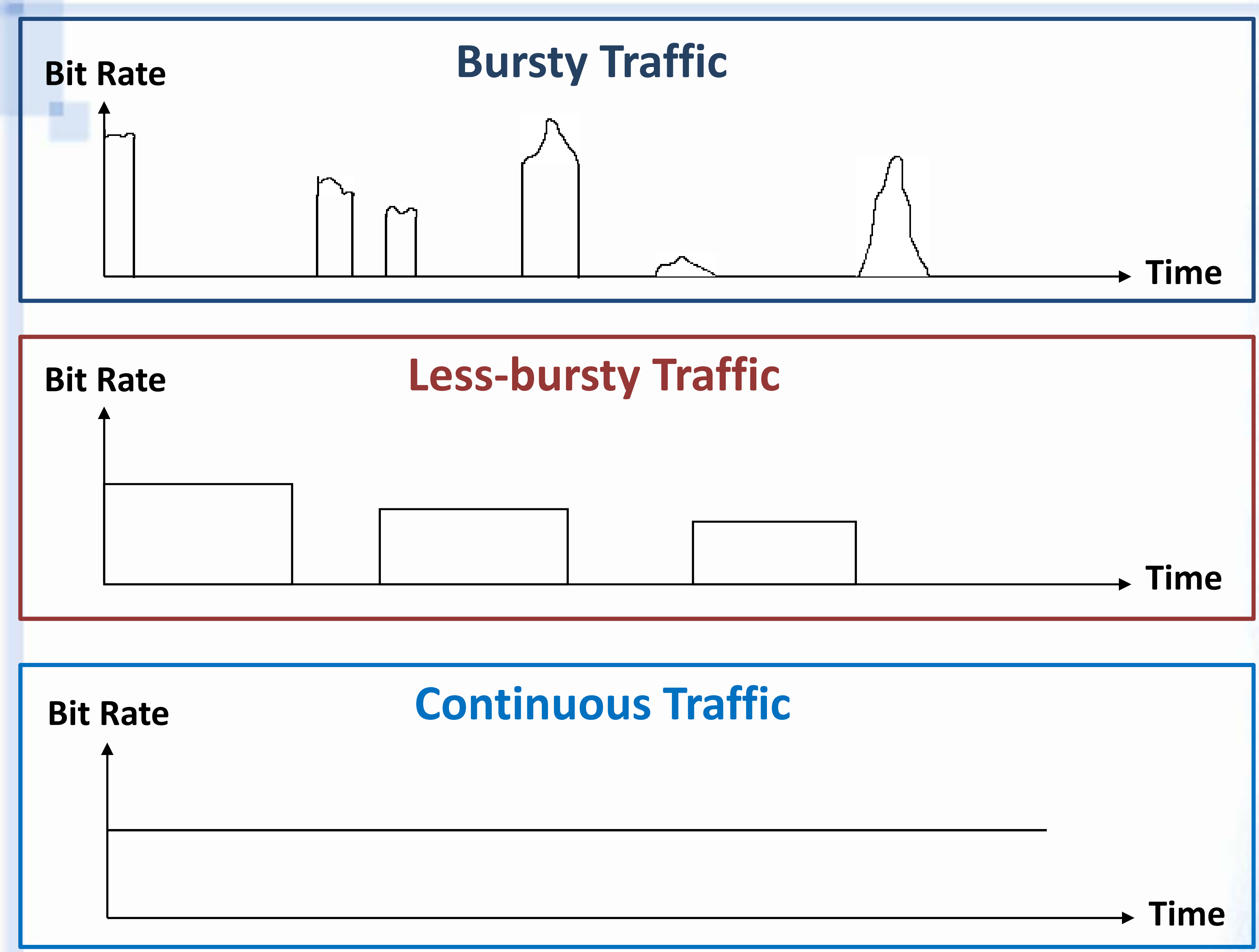


Fig. 1.10. Traffic characteristics of sources of different burstiness

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