Multiplexing, Circuit Switching and Packet Switching

Circuit Switching

- Old telephone technology
- For each connection, physical switches are set in the telephone network to create a physical “circuit”
  - That’s the job of the switching office
Circuit Switching - Example

Physical copper connection set up when call is made

Switching offices

Circuit Switching (cont’d)

• Switches are set up at the beginning of the connection and maintained throughout the connection
• Network resources reserved and dedicated from sender to receiver
• Not a very efficient strategy
  – A connection “holds” a physical line even during “silence” periods (when there is nothing to transmit)
Sharing a Media: Multiplexing

- **Multiplexing** means combining different communication streams into just one communication line
- **Example 1: Frequency-Division Multiplexing**
  - Used by radio, TV and cable TV
  - Different stations transmit over different “channels” (with different frequency)
- **Example 2: Time-Division Multiplexing**
  - For use with digital signals!
  - Used for the communication between telephone switching offices

### Time-Division Multiplexing Example

\[ \begin{align*}
N \text{ streams} \\
R &= \text{sampling rate of each stream} \\
NR &= \text{sampling rate of multiplexed stream}
\end{align*} \]
**Time-Division Demultiplexing Example**

N streams
R = sampling rate of each stream
NR = sampling rate of multiplexed stream

\[00100111000110011000111\ldots\]

\[011111110000001\]

\[100001110011\]

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**Time-Division Multiplexing (TDM)**

- From N streams, each with a bitrate of R bits/s, we generate a single signal with bitrate of N*R bits/s
- Example:
  - Digitized speech with sampling rate \(F = 8\text{KHz}\) and \(B = 8\) bits per sample (\(R = 64\ \text{Kb/s}\))
  - Multiplexing \(N = 24\) streams together creates a stream of 1.5 Mb/s
    - This is the bitrate provided by a **T1 carrier**
TDM (cont’d)

• Resources (time slots on the link) are reserved and allocated to each user
  – Every n-th time slot, the line is dedicated to one predetermined sender
    • How long is the time slot in our previous example?

• What happens if one sender has nothing to transmit?
  – That time slot is wasted!

• NOTE: There is an inherent constant delay
  – E.g., stream #3 has to wait until the first 4 bits of stream #1 and the first 4 bits of stream #2 are transmitted
  – What is the constant delay in our previous example?

Packet Switching

• Sharing by taking turn
  – Model: conveyor belt in a warehouse
  – Items are picked from the storage room and placed on the conveyor belt every time a customer makes an order
  – Different customers may request a different number of items
  – Different users’ items may be interspersed on the conveyor belt (they are “multiplexed”)

• Networks use a similar idea
  – Packet Switching
    • Packetize data to transfer
    • Multiplex it onto the wire
  – Packets from different connections share the same link
**Packet Switching Example**

Each packet is composed by the **payload** (the data we want to transmit) and a **header**
- The header contains information useful for transmission, such as:
  - Source (sender’s) address
  - Destination (recipient’s) address
  - Packet size
  - Sequence number
  - Error checking information
Packet Switching (cont’d)

- The header introduces **overhead**, that is, additional bits to be sent
  - Therefore, it is not wise to have packets that are too small
    - What happens if the payload is just 1 bit?

- **Computer Addresses**
  - Each computer attached to a network is assigned a unique **number** (called **address**)
  - A packet contains the address of the computer that sent it and the address of the computer to which it is sent.

Packet Switching (cont’d)

- In general, packets need not be of the same size
  - The **Internet Protocol** specifies the maximum size
    - Maximum transmission unit (MTU)
  - No minimum size
    - But, header size is fixed (e.g., 20 bytes for TCP/IP)

- Packets are generated by the network hardware
  - The application (e.g., email) does not know that the data to be transmitted is packetized
  - When packets are received, they are put together before the application accesses the data
Packet Switching (cont’d)

• What kind of delay should we expect?
  – Time-division multiplexing: **constant delay**
  – Packet switching multiplexing: **variable delay** (it depends on the traffic on the line)
    • Conveyor belt example: if there are many customers before you, you may have to wait more

• Packetized communication is used by many devices
  – Computer, printers, digital TV, cellular phones,…

Queueing

• What happens when a computer needs to send packets but the link is congested?
  – Needs to “queue” the packets as they are generated before they are transmitted

• What happens when a queue becomes too long?
  – Packets are dropped!

• Queues form (and packets are dropped) also at the intermediate nodes (**routers**)

• How can the receiver detected that a packet was dropped on its way?
  – Look at the packet sequence number!
TDM vs Packet Switching

- Example:
  - 1Mb/s link
  - Users are “active” only 10% of the time
    - A user is “active” when s/he has bits to transmit
  - When they transmit, users send 100 Kb/s streams
    - Hence, only 10 users can be “active” at the same time
- Time-Division Multiplexing:
  - Only 10 user can connect at the same time
    - Every time a user is not active, the time slot is wasted!
- Packet-switching
  - More users can connect
    - As long as no more than 10 users are “active” at the same time! (which will rarely happen)

Circuit Switching vs Packet Switching

**Circuit switching**
- Must set up a connection (initial delay)
- Connection is reliable
- Resources are dedicated
  - Therefore they are used inefficiently!

**Packet switching**
- Very small set-up delay
- Efficient shared use of resources
- Possible congestion and consequent packet dropping