

Multiplexing

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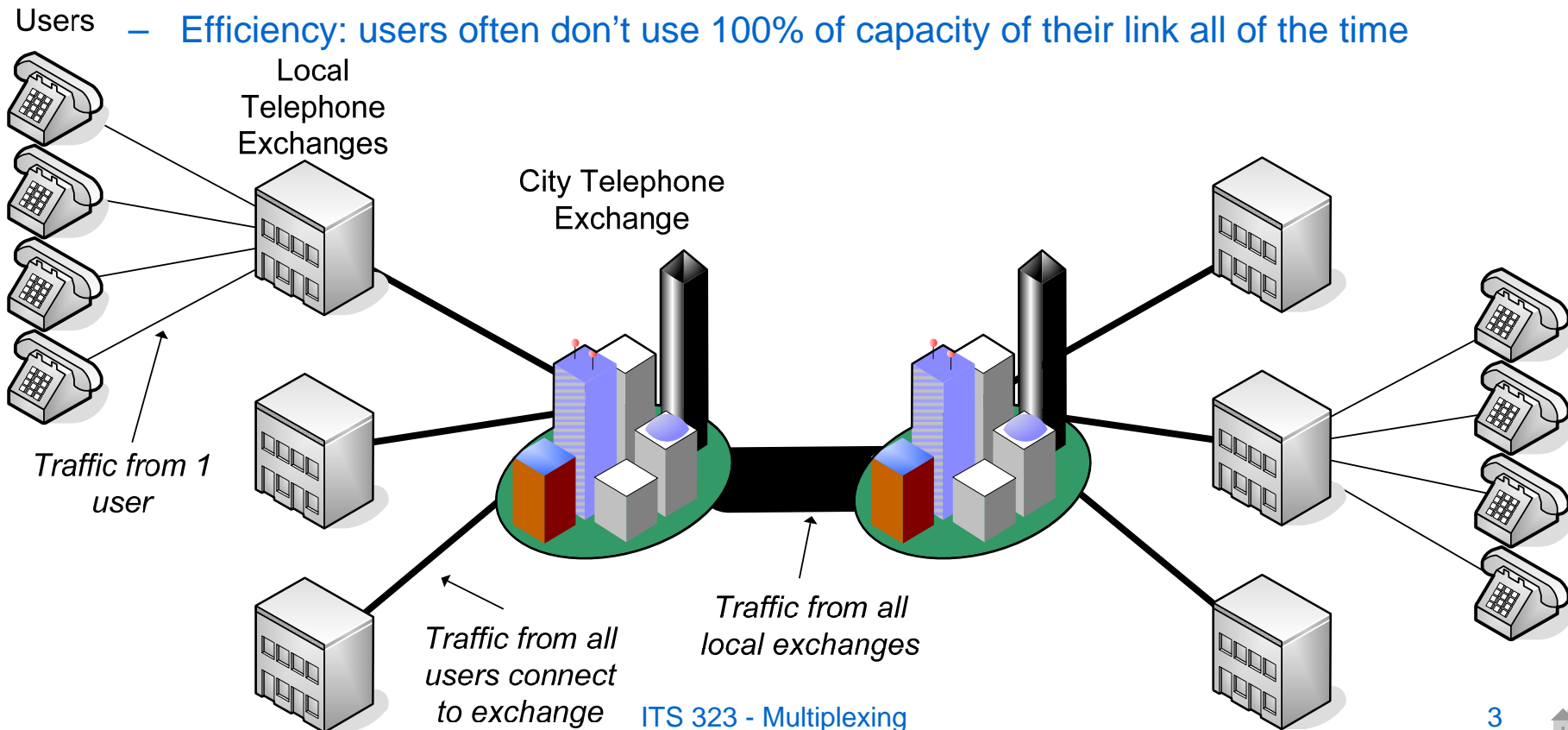
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 - Statistical TDM



Multiplexing

- Multiple stations share the capacity of one link
- Why?
 - Cost: higher data rate transmission system is often more cost effective
 - Better to use 1 optical line at 155Mb/s than 10 DSL copper lines at 15Mb/s each
 - Efficiency: users often don't use 100% of capacity of their link all of the time



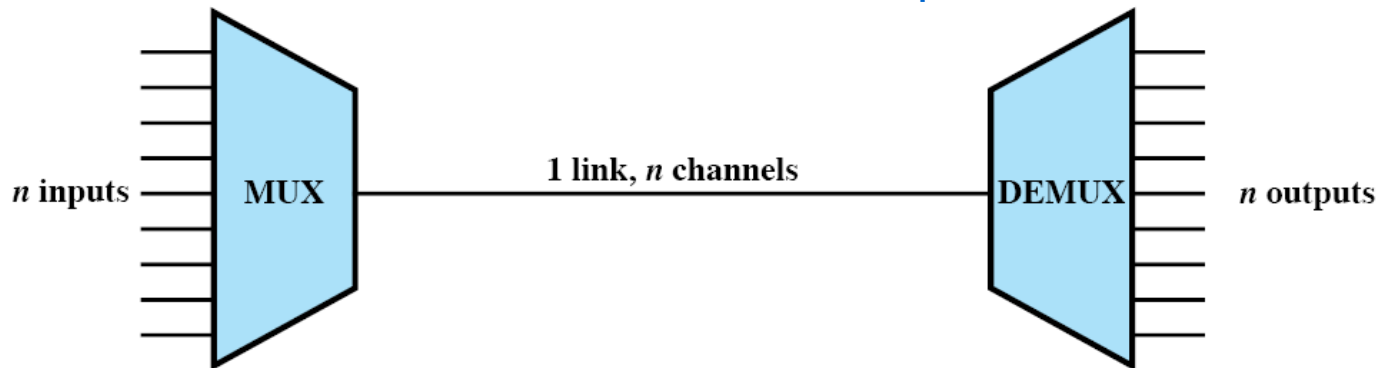
Multiplexing

- Example:
 - 100 users have telephone line connected to Local Exchange
 - Use copper cables from home to exchange
 - Each voice call utilises 4kHz of bandwidth
 - To connect Local Exchange to other Local Exchanges (and Regional/City Exchanges) use:
 - Different transmission media: coaxial cable, optical fibre, terrestrial microwave
 - Combine the traffic (voice calls) from users onto one line (this is multiplexing)
 - The line may be:
 - Enough to support all users: 400kHz bandwidth
 - Support only fraction of users at a time: e.g. 300kHz bandwidth (only 75 users can have a telephone call at the same time; if the 76th user makes a call, they will be blocked)
- Multiplexing: commonly used for long distance, WAN links
 - Telephone systems: analog, fixed; as well as digital mobile phones
 - Internet Service Providers and telecommunication companies
 - Companies connecting LANs via private links



Multiplexing

- Multiplexer (MUX) combines traffic of stations (from input lines) onto one output line
- Demultiplexer (DEMUX) separates traffic from one input line onto multiple output lines (to individual stations)
- Traffic carried between MUX and DEMUX is separated into channels



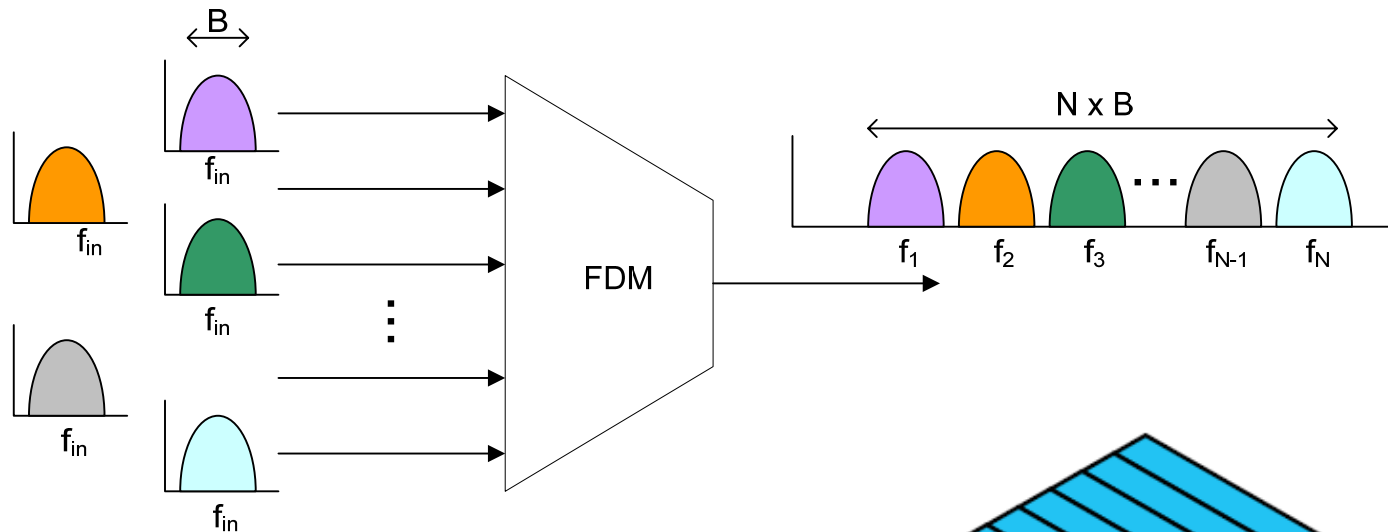
- Different approaches to multiplexing:
 - Frequency Division Multiplexing (FDM)
 - Including Wavelength Division Multiplexing
 - Time Division Multiplexing (TDM)
 - Synchronous TDM
 - Asynchronous or Statistical TDM



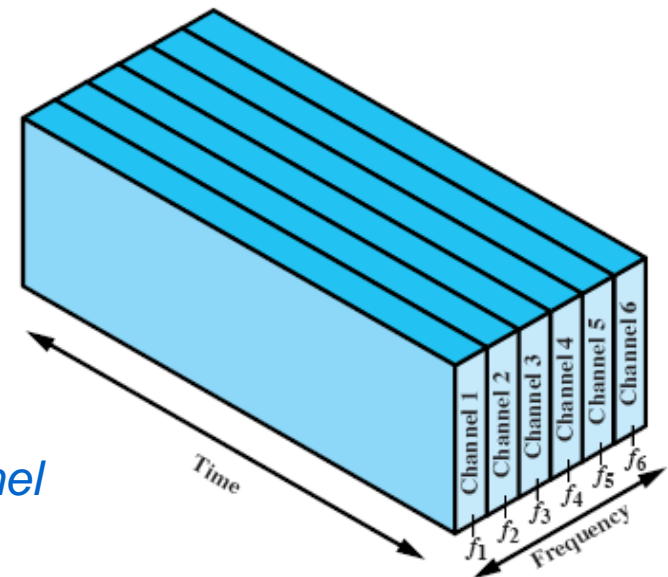
Frequency Division Multiplexing

Frequency Division Multiplexing

- Incoming signals are combined into one output signal by using different carrier frequencies for each incoming signal



- Requires:
 - Bandwidth of output line to be greater than sum of the bandwidths of all input lines
 - Spacing between each signal otherwise they may interfere with each other
- Each signal on carrier frequency is called *channel*

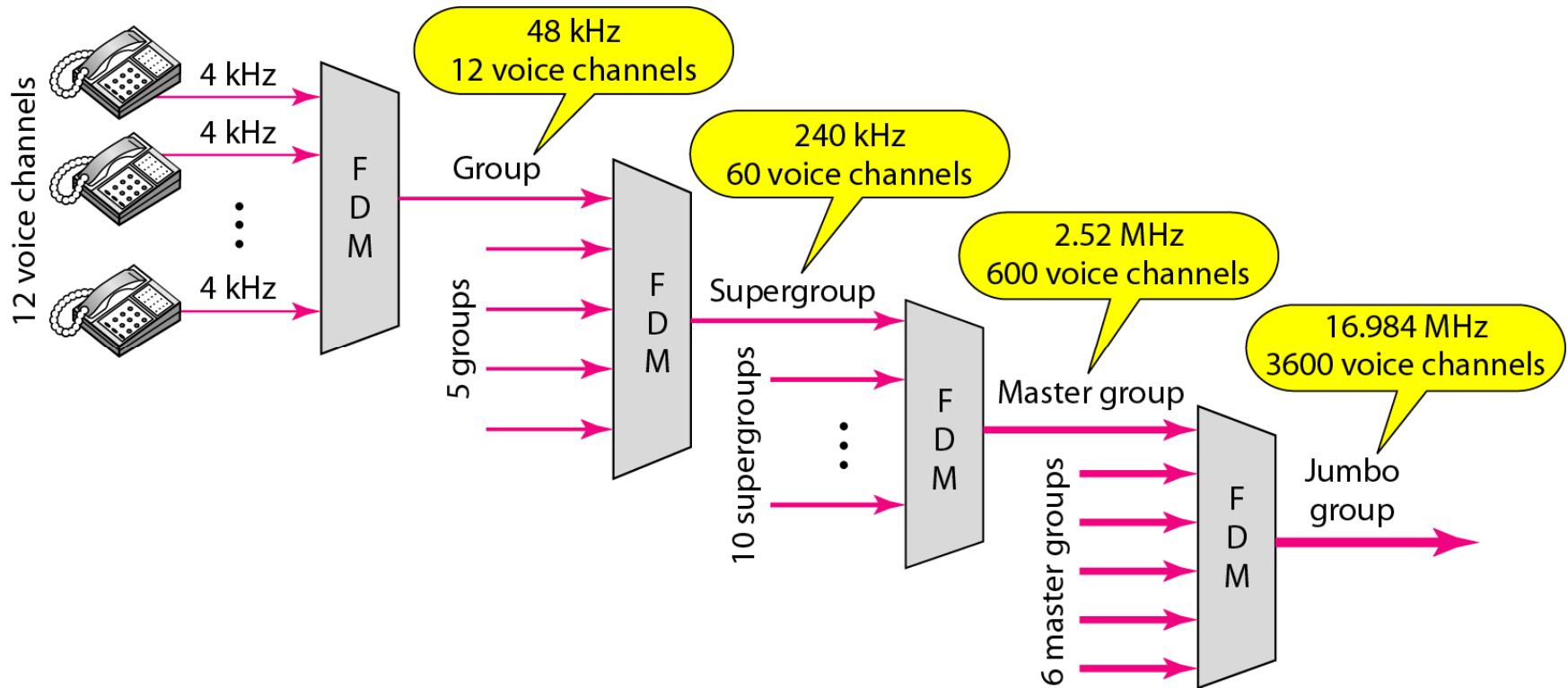


Examples of FDM

- TV distribution
 - For cable TV, the bandwidth of the coaxial cable is 500MHz
 - Many TV programs (bandwidth of 6MHz each) are sent at the same time on the coaxial cable; one program per channel
- Telephone systems (Public Switched Telephone Network, PSTN)
 - Telecommunication companies follow standards for carrying voice channels over long distance links using FDM
 - Hierarchical FDM using coaxial and microwave. Example:
 - The lowest level: each voice channel is 4KHz
 - 12 voice channels combined into group at 60-108KHz
 - 5 groups combined into supergroup at 312-552KHz
 - ...
 - Up to the highest level: jumbogroup containing 3,600 voice channels (frequency approx. 57MHz)
 - Telecommunications equipment designed to support different levels depending on capacity requirement
- There are many other applications of FDM (e.g. ADSL)



Hierarchical FDM Example



Wavelength Division Multiplexing

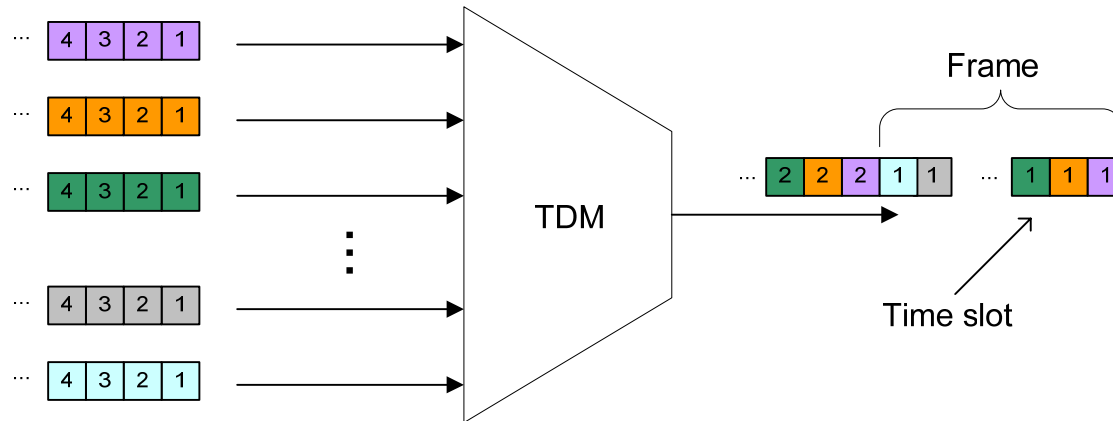
- FDM with multiple beams of light at different frequencies (wavelengths)
- Carried over optical fibre links
 - Commercial systems with 160 channels of 10 Gbps
 - Lab demo of 256 channels 39.8 Gbps
- Architecture similar to other FDM systems
 - multiplexer consolidates laser sources (1550nm) for transmission over single fibre
 - Optical amplifiers amplify all wavelengths
 - De-multiplexer separates channels at the destination
- Also have Dense Wavelength Division Multiplexing (DWDM)
 - Often referred to when channel spacing of around 200GHz



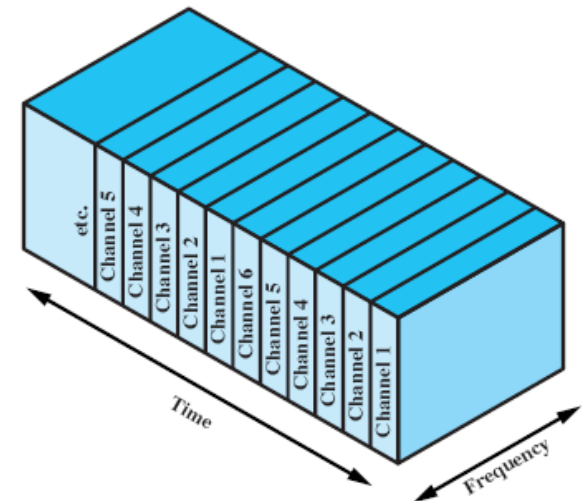
Time Division Multiplexing

Time Division Multiplexing

- Synchronous TDM: Incoming signals are combined into one outgoing signals by interleaving each input signal in time



- Well suited to digital transmission. Interleaving occurs on the bit or byte level
- Requires:
 - Output line data rate greater than the sum of the input line data rates
 - Time slots are pre-assigned to input sources, and ordering is fixed
 - Often slots used for control data



Examples of Synchronous TDM

- Long distance links over copper lines or microwave using TDM hierarchy; called Plesionchronous Digital Hierarchy (PDH)
- In US referred to as T-hierarchy; International (inc. Thailand) uses E-hierarchy
 - Lowest level is a single voice channel, digitised using PCM: 64kb/s
 - E1: carries equivalent of 30 voice channels – 2.048Mb/s
 - E2: carries 4 x E1 (120 voice channels) – 8.448Mb/s
 - E3: carries 4 x E2 – 34.368Mb/s
 - E4: carries 4 x E3 – 139.264Mb/s
 - Used for carry voice and/or data
- Example: SIIT could pay a telecommunications company a monthly rate for an E2 connection between campuses
- Equipment supports combining different levels depending on capacity requirements



Examples of Synchronous TDM

- Synchronous Digital Hierarchy (SDH)
 - Referred to as SONET in US
 - Improves open PDH
 - Uses optical fibre instead of copper cables
 - Many network management functions included in SDH

<i>SDH Speeds</i>	
Name	Mb/s
STM-1	155
STM-4	620
STM-16	2500
STM-64	10000

- Used by large ISPs, telecommunication companies for links across cities, between cities and between countries



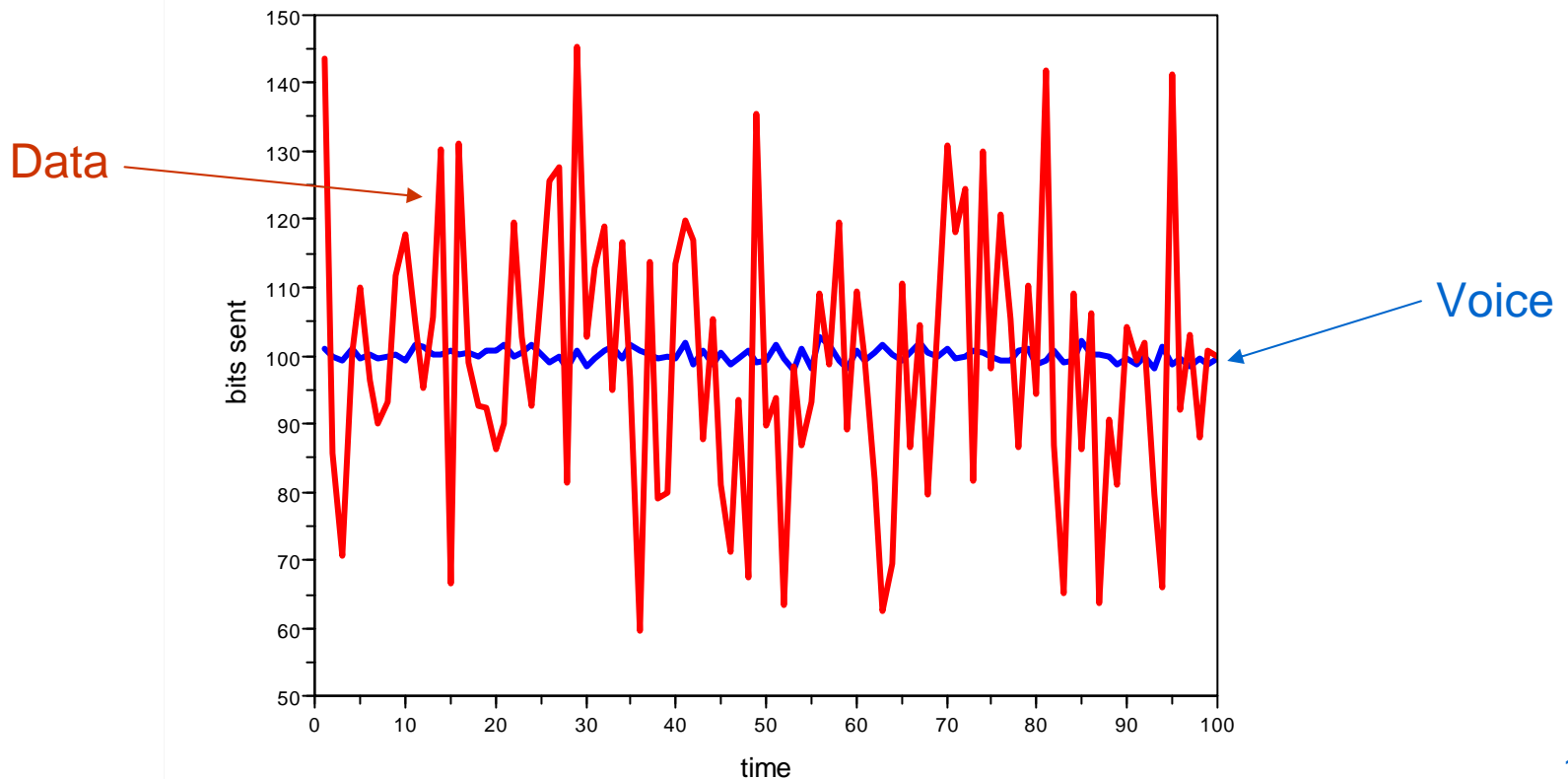
Advantages and Disadvantages of Synchronous TDM

- Synchronous TDM
 - Each time slot is pre-assigned to the input lines
 - Consider 4 input lines, with each user making a voice call
 - Using PCM, each user generates 8000 bytes per second; assume 1 byte per time slot
 - With voice calls, the data generated is reasonable constant over time
 - Time slot 1 will contain first byte from user 1; time slot 2 first byte of user 2; and so on
 - No need to identify whose data is carried in each time slot; DEMUX knows: data in time slot 1 goes to user 1; data in time slot 2 goes to user 2; and so on
 - Output line would be 256kb/s
 - Now, consider each user instead sending requests for web pages
 - Sometimes user 1 will have a lot to send, while user 2 will have nothing to send
 - With web traffic, the data generated varies significantly over time
 - But synchronous TDM assigns a slot to each user, if the user has nothing to send, then the time slot is wasted (nothing is sent by anyone)
 - Synchronous TDM can become very inefficient with some data traffic



An Aside: Voice and “Internet” Traffic

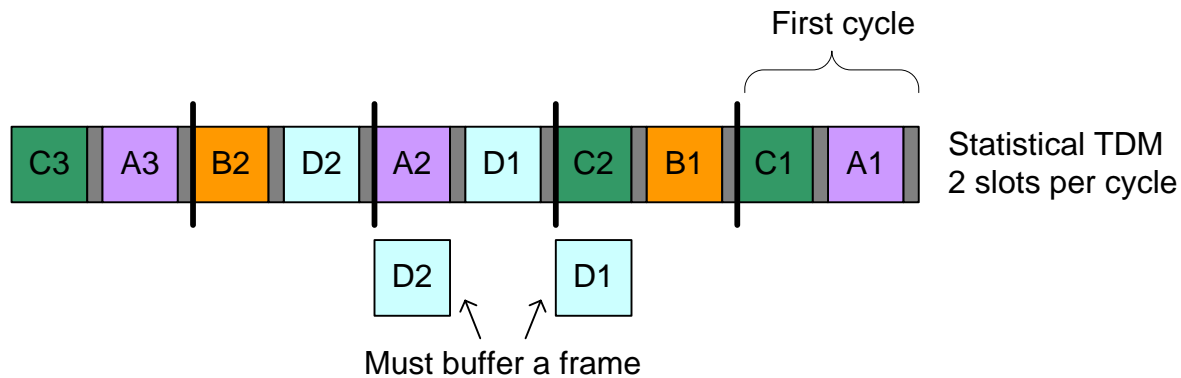
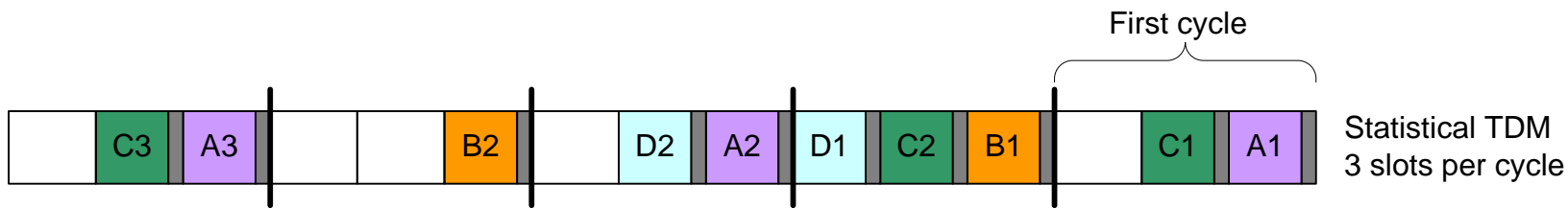
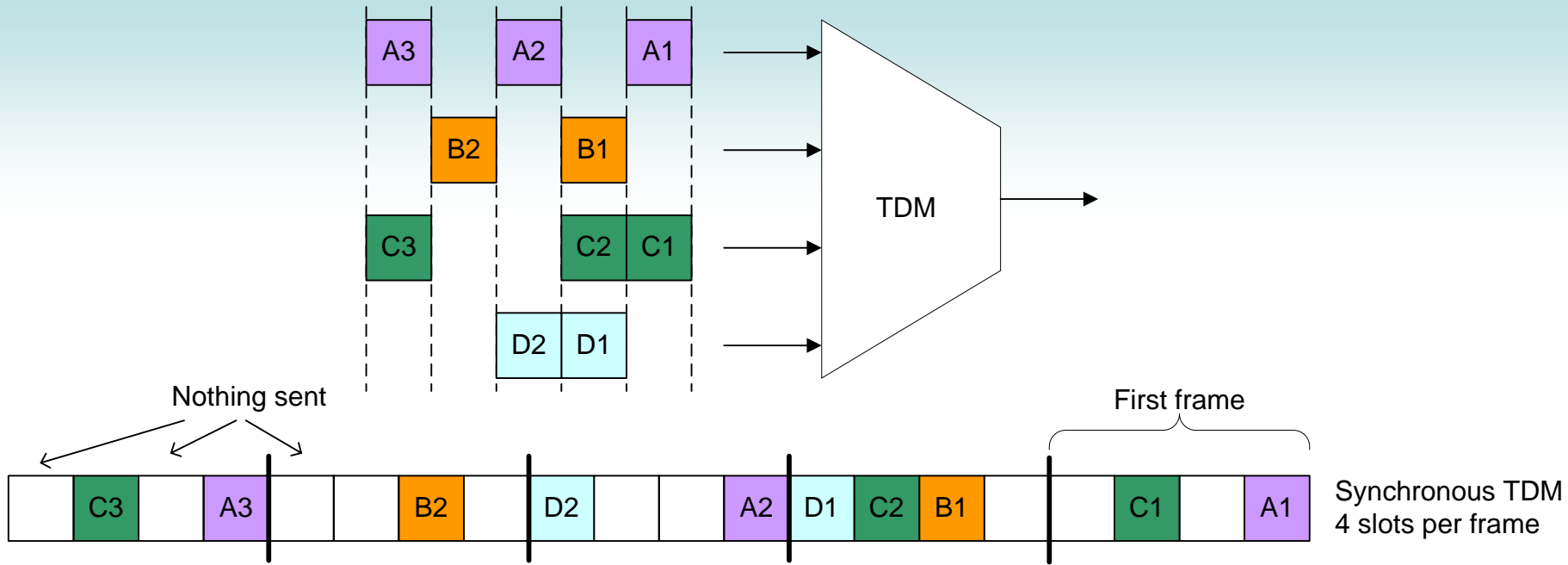
- When you are making a voice call, the amount of data to be sent (and received) is reasonably constant over time
- When you are browsing the web, the amount of data to be sent (and received) varies significantly over time



Statistical TDM

- Statistical (or Asynchronous) TDM allocates time slots dynamically based on demand
 - If a source has no data, then the multiplexer can send data from another source
 - Multiplexer scans input lines and collects data until frame full
 - Output line data rate can be lower than the sum of input line rates
 - Assumes that the average input data to be sent is lower than line data rate
 - E.g. if we have 4 input lines each of 1Mb/s, but with only being utilised 75%, then the output line rate could be 3Mb/s
 - However, may have problems in peak periods (that is, when all inputs produce peak data)
 - Must buffer inputs, causing possible delays and dropped data
 - Requires:
 - Extra headers for each time slot, so the DEMUX can identify which user the data is delivered to





Synchronous vs Statistical TDM

- Assumptions:
 - Time slot is $80\mu\text{s}$ and each block of data is 10 bytes
 - Input line rates are therefore 1Mb/s
 - Arrival rate of input data varies between users (A & C: 600kb/s; B & D: 400kb/s)
- Synchronous TDM
 - Each frame is $80\mu\text{s}$
 - Output line rate is 4Mb/s
 - Line utilisation (efficiency): 50%
- Statistical TDM
 - Assume in each cycle, MUX scans the 4 input data lines and tries to send the blocks of data available
 - Each block needs a header; lets assume it is 2 bytes in length
 - If send 3 blocks per cycle ($80\mu\text{s}$):
 - Output line rate of 3.6Mb/s could be used; utilisation of 55%
 - If send 2 blocks per cycle ($80\mu\text{s}$):
 - Output line rate of 2.4Mb/s could be used: utilisation of 83%
 - However, must have a buffer for at least 1 block (40 bytes)



Synchronous vs Statistical TDM

- Synchronous TDM
 - Time slots are pre-assigned, ordering is fixed
 - Good if arrival rate of data is constant and close to the rate of output line
 - E.g. voice, video traffic
 - Output line rate must be greater than sum of input line rates
 - No headers are needed
 - No buffers are needed
- Technology: PDH, SDH, Mobile phones, satellite transmission, ...
- Statistical TDM
 - Time slots are dynamically assigned on demand
 - Good if arrival rate of data varies
 - E.g. web and other data/Internet traffic
 - Output line rate is often less than sum of input line rates
 - Each block (frame) contains a header (extra complexity at receiver to process header)
 - When input data arrives at peak rates, either buffers are used or data is dropped
 - Buffers introduce delay/jitter
- Technology: Asynchronous Transfer Mode (ATM) used by ISPs, Telcos

