UNIT 6
ANALOG COMMUNICATION & MULTIPLEXING

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Syllabus

- Multiplexing,
  - Frequency-Division Multiplexing
  - Time-Division Multiplexing
  - Space-Division Multiplexing
- Combined Modulation Systems
- Functions within Analog Communication System
- Shortcomings of analog communication and Multiplexing
- A medium can carry one signal at any moment because if there are two signals over there, they are going to interfere.

- For multiple signals to share one medium, the medium must somehow be divided, giving each signal a portion of the total bandwidth.
Why Multiplexing
Multiplexing vs. No Multiplexing

a. No multiplexing

b. Multiplexing
Need of Multiplexing

- Transmission service is very expensive (example - Leased line)
- Data link capacity utilization is inefficient.
- More than one signals/message can be sent over single medium or link
MULTIPLEXING

- Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared.

- **Multiplexing** is a technique that allows the simultaneous transmission of multiple signals across a single data link.
Multiplexing

Frequency-division multiplexing (FDM)

Time-division multiplexing (TDM)

Synchronous

Asynchronous
FREQUENCY DIVISION MULTIPLEXING
In FDM, Frequency-division multiplexing (FDM) is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted.
In FDM, signals generated by each sending device modulate different carrier frequencies.

These modulated signals are then combined into a single composite signal that can be transported by the link.

Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal.

Channels can be separated by strips of unused bandwidth (guard bands) to prevent inter-channel cross talk.
FDM (Time Domain)
Multiplexing, Frequency Domain
Demultiplexing (Time Domain)
Demultiplexing (Frequency Domain)
FDM (Time Domain)

http://www.mhhe.com/engcs/compsci/forouzan/dcn/graphics/animations/08_04.swf
Exercise 1

- Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz.

- Show the configuration, using the frequency domain. Assume there are no guard bands.
Solution

Shift and combine

Higher-bandwidth link

Filter and shift
Exercise 2

- Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10kHz between the channels to prevent interference?
Solution

- For five channels, we need at least four guard bands. This means that the required bandwidth is at least $5 \times 100 + 4 \times 10 = 540$ kHz.

![Diagram showing five channels with guard bands of 10 kHz each, totaling 540 kHz.]
Advantages

- Simultaneous Transmission of data of multiple user
- Simple
- Cheap
- Most popular
Disadvantages

- Limited Bandwidth (Cannot utilize the full capacity of the channel)
- More prone to noise
- Wastage of bandwidth is more
Applications

- BROADCAST RADIO (AM, FM)
- CABLE TV
- AMPS cellular system
Analog Hierarchy

12 voice channels

4 KHz

4 KHz

4 KHz

Group

5 groups

48 KHz
12 channels

240 KHz
60 channels

2.52 MHz
600 channels

16.984 MHz
3600 channels

FDM

FDM

FDM

FDM

FDM

FDM

Supergroup

10 supergroups

Mastergroup

6 mastergroups

Jumbo group
FDM

- AM (amplitude modulation) Band uses amplitude modulation in FDM scheme to allow multiple stations in (550 – 1650 KHz)
- Similarly FM (frequency modulation) Band uses frequency modulation in FDM scheme to allow many stations in (88 -108 MHz)
Multiplexing, Frequency Domain

Multiplexer

mod

f1

mod

f2

mod

f3

Sending bandwidth
FDM

- **Addition of user**
  - Once path is set up, expense only includes cost of modulator and demodulator
  - Maximum user limit

- **Failure of FDM**
  - Channel fails
  - Modulator malfunctions
    - Puts out signals with the wrong carrier value
    - Improper modulation that spills into other user sidebands
FDM

- Carrier frequency assignment & bandwidth utilization
  - Sending different type of signals (Example - Space vehicle to earth station based communication)
    - Video (Bandwidth required 6MHz)
    - Audio (Bandwidth required 3 kHz)
  - Sending approximately same signals
    - Easier to divide the spectrum evenly

- FDM used for full duplex communication
  - It allows the same physical link to be used while both talk at a time.
Wavelength Division Multiplexing

- Conceptually *same as FDM* except that multiplexing and demultiplexing involves *optical signals*.
- Optical fiber medium provides enormous bandwidth.
- Wavelength Division Multiplexing is commonly used in case of optical fiber.
Wavelength Division Multiplexing

- Prism bends beam of light based on the angle of incidence and the frequency of light wave.
TIME DIVISION MULTIPLEXING
TIME DIVISION MULTIPLEXING

- Digital multiplexing technique that allows several connections to share the high bandwidth of a link.
- Instead of sharing bandwidth as in FDM, *time is shared*.
- TDM is serial system
• **Single path and carrier frequency** is used
• Each user is assigned unique slot
• Goes from one user to other in some specific sequence and time
TDM Physical analogy

- Rotary Switch
- Microprocessors have multiplexed data/address bus to reduce the number of pins.
Types of TDM

- Synchronous TDM
- Asynchronous TDM
Synchronous TDM (STDM)

- Each device is given equal Time Slot to transmit the data over the link, whether the device has any data to transmit or not.
- Each device places its data onto the link when its *Time Slot* arrives, each device is given the possession of line turn by turn.
- If any device does not have data to send then its time slot remains empty.
- Time slots are organized into *Frames* and each frame consists of one or more time slots.
- If there are *n* sending devices there will be *n* slots in frame.
Synchronous TDM

Data are taken from each line every $T$ s.

Each frame is 3 time slots. Each time slot duration is $T/3$ s.
TDM, Multiplexing
TDM, Demultiplexing
Disadvantages of synchronous TDM -:

- The channel capacity cannot be fully utilized because some of the slots go empty in certain frames.
Asynchronous TDM
Asynchronous TDM (ASTDM)

- In this time slots are not fixed i.e. slots are **Flexible**.
- In ASTDM we have $n$ input lines and $m$ slots i.e. $m$ less than $n$ ($m<n$).
- Slots are not predefined rather slots are allocated to any of the device that has data to send.
- Also known as **Statistical Time Division multiplexing**.
Asynchronous TDM

Number of inputs: 5
Number of slots in each frame: 3
Frames and Addresses

a. Only three lines sending data
Frames and Addresses

b. Only four lines sending data
Frames and Addresses

c. All five lines sending data
STDM v/s ASTDM

Synchronous TDM

Asynchronous TDM
Real-time Scenario

- Temperature Monitoring of a building

Temperature Sensor 1

Temperature Sensor 2

Temperature Sensor 3

Temperature Sensor 4

Temperature Sensor 5
Real-time Scenario

- Temperature Monitoring of a building

Temperature Sensor 1
Temperature Sensor 2
Temperature Sensor 3
Temperature Sensor 4
Temperature Sensor 5

TDM Circuit
Channel Identification

Temperature Sensor 1
Temperature Sensor 2
Temperature Sensor 3
Temperature Sensor 4
Temperature Sensor 5

TDM Circuit
Channel Identification

**Method 1**

Channel Number or code to each signal

Channel Identifiers
Channel Identification

**Method 1**

- Channel Number or code to each signal
- Receiver circuitry has to check each signal for this code

**Advantages**:
- *Simple & Effective*

**Disadvantages**
- *Sending code occupies time on the signal link (Link not utilized up to a fullest extent)*
Channel Identification

Method 2
Synchronisation

- At start sync signal is sent from Transmitter to tell receiver that next group of time multiplexed signal is about to begin

Advantages:
- Higher data rate
- Greater Channel utilization efficiency

Disadvantages:
- Greater complexity and system cost
TDM

Advantages:

1. No precise Carrier matching required (since only one carrier is used)
2. It is easy (simple & at low cost) to expand the number of users
3. No new circuitry is needed at transmitter or receiver and link doesn’t have to be changed for addition of users
4. Compatible to Computers (since have internal clocks)
TDM

Disadvantages:

1. Since only one transmitter, link & receiver, so all user suffer if there is problem with these

2. Keeping Clocks of two systems in synchronization at high rate difficult

3. Limited TDM rate because of data rate of link or noise & distortion problems of link
Applications

- Used extensively at service provider side
- Telephone companies implement TDM through a hierarchy of digital signals, called digital signal (DS) service

<table>
<thead>
<tr>
<th>Service</th>
<th>Line</th>
<th>Rate (Mbps)</th>
<th>Voice Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS-1</td>
<td>T-1</td>
<td>1.544</td>
<td>24</td>
</tr>
<tr>
<td>DS-2</td>
<td>T-2</td>
<td>6.312</td>
<td>96</td>
</tr>
<tr>
<td>DS-3</td>
<td>T-3</td>
<td>44.736</td>
<td>672</td>
</tr>
<tr>
<td>DS-4</td>
<td>T-4</td>
<td>274.176</td>
<td>4032</td>
</tr>
</tbody>
</table>
Space Division Multiplexing

- There is a physical link or path dedicated to each sender and receiver pair.

- Example: Standard Telephone and local telephone office (Each phone is connected to local office by a pair of wires that no other phone shares)

- In SDM systems signal is usually modulated as Amplitude modulation.
SDM

- Used for short distances (few miles)
Advantages of SDM

- Simple to build
- Any problem in one link will not affect other users.
- It is easy to add users.
- Performance of SDM system is predictive and guaranteed.
Disadvantages

- Initial cost of laying cables, tunnels, telephone poles is very high.
- As the number of users increases cost will increase proportionally.
- Poor Link utilization (Most of the time link remains unused).
Application

- Telephone user to local exchange connection
- SDM is used in critical applications like military and industries
Combined Modulation Systems

- Wide range of user needs & various physical separations of users necessitate that overall user to user system be composed of several independent links.
- At each link incoming signals are demodulated and then combined with those of other users.

- Purpose of this process is to provide **most efficient** total systems for various numbers and group of users.
  - Best technical performance
  - Lowest cost
  - Maximum flexibility to handle differing number of users
- **SDM** path from New York phone to New York Central office of that phone & Los Angeles phone to Los Angeles Central office of that phone
- **FDM** link combining many long distance users of this central office to the next level (regional office)
- **TDM** a very high performance and distance link via microwave link from the east coast regional office to West coast central office
Combined Modulation Systems

- Role of various links is to
  - **Gather together** many users who are going towards the same destination,
  - **Modulate** them as a group of users
  - **Send** them down the link

- Combined modulated systems can also use same type of modulation for successive links but implemented with different carrier frequencies or time slots
Combined Modulation Systems

- Central Office
- Regional Office
- Larger Regional Office

- FDM
- SDM
Combined Modulation Systems

- Even though user signal is modified by the modulator as it passes through the FDM or TDM systems, it is restored to original shape and form by the demodulator.

- This means link is **transparent** to the user signal.

- The modulation and demodulation systems does not actually examine the contents of the message.

- **Transparent link** allows users to have to have greater **flexibility**.
Shortcomings of Analog communications & Multiplexing

- Shortcomings is due to fact that using analog signals to convey information.

- Noise can
  - Corrupt the desired signal and
  - Reduce signal accuracy.
  - Cause problems for receiver circuitry if demodulator has to synchronize to the received signal

- Noise problem for analog multiplexing effect has greater effect on TDM, lesser effect on FDM and least on SDM
Shortcomings of Analog communications & Multiplexing

- **TDM** most effected
  - One chance to receive signal for short time period
  - Sync signal may get corrupted. So receiver can’t synchronize

- **SDM, FDM** – Noise effects only few users

- **FDM** – Noise affected only small range of frequencies

- **SDM** – Separate link
Shortcomings of Analog communications & Multiplexing

- Sometimes individual readings are important (scientific & numerical values) and sometimes average value should approximate same to original value (audio, music)

- Multiplexing systems should not introduce any distortion and non-linearities when it combines various user signals.

- Any imperfection in Multiplexer, modulators, demodulators, de-multiplexer lead to error and inaccuracies in the received signals which are indistinguishable from the correct values.
- If analog signal is corrupted by noise it is even difficult to detect the error
- Sometimes two users are assigned to carry the same message (say 5.4)
  - However this is expensive and
  - doesn’t guarantee that error can be detected (since if both signal gets distorted).
  - Sent 5.4 (both user receive 5.2)
  - Sent 5.4 (one user receive 5.6, other user 5.2)

- I m a cat → I m a cit
Methods to ensure that signal received is proper or with errors

1. Send the message again (after some time) or Send the message in multiplex system as another user on system
   - *Consumes system time or uses another user link*

2. Send special signal after message signal. (Value of this signal may be average of message signal values)
   - *It is just summary*

3. Send pair of signals equal to *largest* value of message and then the *smallest*. This could be used to calibrate the communication systems to see how it performs at either extreme of it’s capabilities.
   - *System problems & noise varies with time*