Data Communications

Introduction

Communications Tasks

- To allow two remote entities to communicate with each other effectively and efficiently.

Communications Model

Source → Transmitter → Transmission System → Receiver → Destination

- Source : Device that generates data
- Transmitter : Transforms and encodes data
- Transmission System : The physical system connecting the source and the destination devices
- Receiver : Performs reverse function of transmitter
- Destination : Receives the incoming data.

• Transmission signal - either some form of electro-magnetic wave (EM) or an electrical signal.
  - Alternating Current, Voltage pulses, etc
  - Simplest form of signal is a sine wave

• Transmission System - A transmission medium, such as →
  ↳ Guided - Electric cable, optic cable
  ↳ Unguided - EM waves in space

• Successful data transmission depends on →
  • Quality of the transmission signal
  • Characteristics of transmission system / medium

Signal Analysis

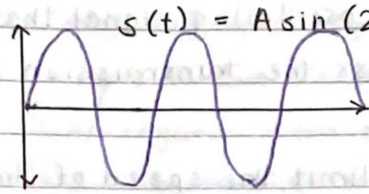
Signal Characteristics

• Continous - No breaks or discontinuities within signal
• Discrete - Contains a finite number of discrete values
• Periodic - Repeats itself after some fixed time
• Aperiodic - No repetition of signal patterns

Sine Wave Characteristics

- General equation applied -

$$s(t) = A\sin(2\pi \cdot ft + \phi)$$

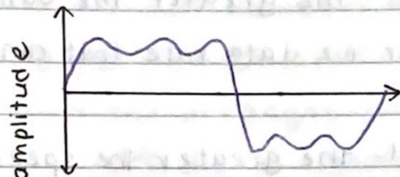


A = amplitude

f = frequency in Hertz (Hz)

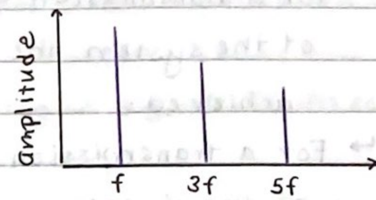
ϕ = Phase (relative position in degrees or radians)

Time Domain and Frequency Domain



time domain (secs)

Shows how a signal changes over time



frequency domain (Hertz)

shows how signal is distributed within different frequency bands over a range of frequencies

Signalling Concepts

- Spectrum - Range of frequencies contained in a signal
- Absoute Bandwidth - width of the spectrum
- Effective Bandwidth
  - ↳ Signals with spharp rising and falling edges in the time domain have very wide absolute bandwidth
    - ↳ Most energy is contained in a relatively narrow band called Effective Bandwidth.
- DC Component - Signal with a component at 0 frequency.

Transmission System Bandwidth

- All transmission (Tx) systems are limited (restricted) in the range of signal frequencies they can carry
  - ↳ This restriction is called System Bandwidth -
    - Results from the physical components that make the system
    - Physical properties of matter and energy

Data Rate & Bandwidth

- Bandwidth of transmission system can be -
  - ↳ The fastest continously oscillating signal that can be sent (transmitted) across the transmission system. Represented in Hertz.
    - ↳ The effects are to limit the speed of transmission of data (data rate).
  - ↳ For a transmission system - the greater the bandwidth of the system the higher the data rate that can be achieved.
  - ↳ For a transmission signal - the greater the speed (frequency) of the signal -
    - the greater the bandwidth of the signal
    - the more data can be transmitted.

Data and Signals

- Analogue Data - Take on continous values on some interval ex- voice, pressure, etc
- Digital Data - Take on discrete values, ex - integers, text, etc
- Analogue signal - Continously varying electromagnetic wave (representing data) that may be propagated over a transmission system
- Digital Signal - Sequence of discrete - discontinuous voltage pulses (representing data) that may be propagated over a transmission system.

- Data transmission is the communication of data by the propagation and processing of signals, such as -
  - → Analogue data can be conveyed by an analogue signal
  - → Digital data can be conveyed by an analogue signal when a MODEM is used
  - → Analogue data can be conveyed by a digital signal.
  - → Digital data can be conveyed by a digital signal.

- Analogue Transmission
  - the propagation of analogue signals only, ex- some physical quantity (ex-voltage) that changes continuosly as a function of time.
  - no regard to the content (the encoded data) of the signal.
  - as the transmitted analogue signal becomes attenuated with distance - an amplifier can extend the range.
    - however this boosts noise which can distort signal.
- Digital Transmission
  - the propagation of analogue signals (with encoded digital data) OR digital signals
  - has regard to the encoded data of the signal
  - the transmitted digital signal becomes attentuated with distance a repeater can extend the range
    - a repeater receives the attenuated signal, recovers the digital data and re-transmits a new signal with no noise added.
- Digital or Analogue Transmission (digital is superior)
  - low cost of digital electronics
  - data integreity - signal can be maintained without noise
  - capacity utilisation - different digital signals can be 'multiplexed' and 'de-multiplexed' more easily and thus share a signal channel
  - security - encryption can be more easily applied to digital data.
  - integration - digitised analogue data can be mixed with digital and share same facilities as other digital data

Data Encoding

- Data is propagated from point to point by encoding data onto signals (this data can be digital or analogue)
  - Devices that produce signals →
    - CODECs produce digital signals
      - → Excellent for transporting computer data ~~voice and video data~~ as it is already in digital form ~~as they are traditionally in analogue form~~
      - → Analogue data can also be carried
    - MODEMs produce analogue signals
      - → Excellent for transporting voice and video data as they are traditionally in analogue form
      - → Allows for transmission of digital data across transmission systems that can only deal with analogue signals.

Digital data onto digital signals

- Binary data are transmitted by encoding each data bit into signal elements
- Each signal element may represent one or more data bits
- More definitions and terminology →
  - Signal elements →
    - → Digital = A voltage pulse of constant amplitude
    - → Analogue = A pulse of constant frequency, phase and amplitude
  - Unipolar = All signal elements have the same algebraic sign → all are +ve or -ve.
  - Polar = Signals can have different algebraic signs
  - Mark/Space = Refers to binary one/zero
  - Data Elements = bits
  - Data Rate = The rate at which data is transmitted (bits per second)
  - Modulation Rate = Rate at which signal level is changed per second.
    - ↳ represents the number of signal elements transmitted per second and is expressed in Baud.

↳ Bit rate and Baud are equal if - only one signal element represents one bit

$$D = R / b$$

D = modulation rate, R = Data Rate, b = bits per signal

- Bit Duration = time to transmit one bit

Digital Signals Encoding Schemes

- NRZ schemes
  - Non-Return to Zero scheme
  - NRZ techniques →
    - NRZ-L
      - ↳ easiest way to encode data
      - ↳ used by computer terminals and other devices
      - ↳ easy to implement
      - ↳ level (amplitude) and polarity are important
    - NRZI
      - ↳ type of differential encoding (not examinable)
  - make good use of bandwidth - on average one bit per signal elements
  - limitations
    - ↳ precence of a DC component
    - ↳ poor synchronisation
- Multilevel Binary Schemes
  - Multilevel Binary Techniques →
    - ~~Binary~~ Bipolar AMI - space represented by no line signal, this means zero volts and mark is represented by +ve and -ve mark.
    - Pseudoternary (not examinable) but very simpilar to
    - Both techniques use 3 signal/voltage levels
  - Advantages
    - ↳ No DC component
    - ↳ synchronisation is easier
    - ↳ Provides simplistic means of error detection.

- disadvantages
  - less efficient in terms of number of encoded bits per signal level
  - more voltage changes for the same number of bits
  - forces the receiver to work harder to interperet bits

• Biphase schemes
- Techniques to look for →
  • Manchester
  • Differential manchester (not examinable)
- advantages
  - modulation rate is twice that for NRZ
  - synchronisation is provided within each bit interval
  - no DC component
  - better low level error detection
  - good performance in presence of noise

! Comparison of all digital signal endoding schemes →

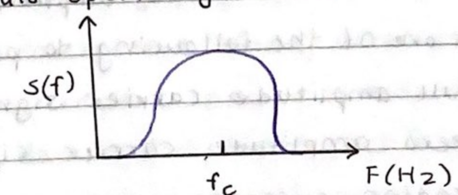
	NRZ	Multilevel Binary	Biphase
Bandwidth ~~Bandwidth~~	smallest	Same as NRZ	Double of NRZ
DC Component	Presence of DC component leads to power wastage	Zero DC component	Zero DC component
Synchronisation	String of continuous 1s and 0s leads to loss of synchonisation	String of continuous 1s and 0s leads to loss of synchronisation	Transition at middle of pulse allows synchoronisation
Error Detection	No capability	No capability	Built in capability because of transition
Maximum Modulation Rate	Same as data rate - NRZL: for 1010... NRZI: for 1111...	Same as data rate - Bipolar: for 1111... Pseudo: for 0000...	Double of data rate - For 0000...

Reading Digital Data off Digital Signal

- To intepret a digital signal, the receiver must →
  - → be able to read the signal elements ex - voltage level
  - → know when a bit starts and ends (bit duration = timing)
- Successful reception of data depends on →
  - → Adequate signal to noise ratio
  - → Sufficient bandwidth
  - → Sufficietly low data rate.

Digital Data / Analogue Signals

- Modulation - technique used to encode digital data onto an analogue signal
- Sine waves have 3 characteristics that can be modified
  - → Amplitude
  - → Frequency
  - → Phase
- When viewed in the frequency domain, the modified carrier signal can be seen to have a bandlimited (fixed range) spectrum centered on f_c. →
  - → This spectrum can be considered as a channel through which data passes
  - → Other channels can be created using other carrier signals operating at different distinct frequencies

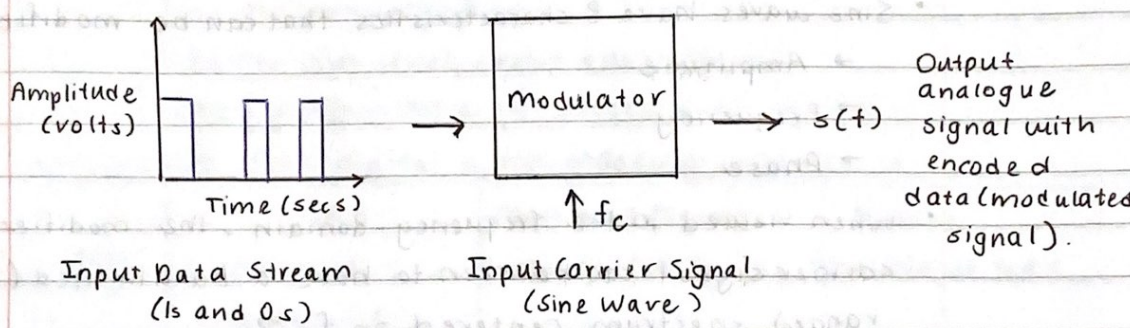


- Applications for modulation
  - Transmission of digital data across the Plain old Telephone system (PoTS)
    - ↳ designed for transmission of analogue voice
- Resultant modulated analogue signal is in voice-frequency range →
  - → approximately 400 - 4000 Hertz.

• Modulator

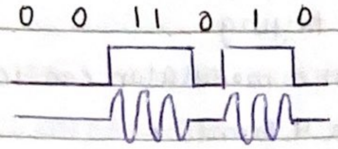
- with each technique, the modulator can be considered as having 2 inputs →
    - one input for the data stream (1s and 0s)
    - one for the carrier signal (sine wave of frequency)
- the modulator modifies one of the parameters of the carrier signal to represent the data
    ↳ the modulated carrier signal is passed to output of the modulator

! data input exists but the carrier signal is used for explanation, does not exist.



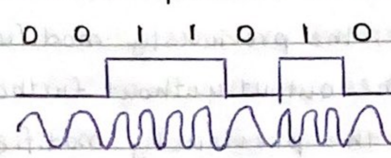
• Modulation Techniques

- Amplitude Shift Keying
    ↳ Representing data using two or more amplitudes
    ↳ modulator modifies the amplitude of carrier signal
    ↳ allows one of the following to pass the output →
        - full amplitude carrier signal
        - zero amplitude carrier signal
    ↳ for encoding purposes - the rules are →
        - to encode a binary zero (space) the zero amplitude carrier is passed to the output
        - to encode a binary one (mark) the full amplitude carrier is passed to output.



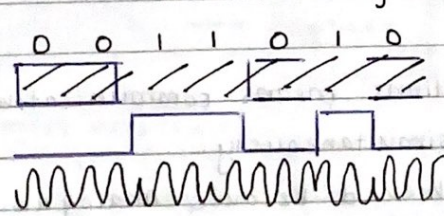
Example of ASK

- Frequency Shift Keying
  - ↳ Representing data using two or more different frequencies
  - ↳ Modulator can be considered having access to 2 other signals →
    - one operating at frequency f_1
    - one operating at frequency f_2
  - ↳ for encoding purposes, the rules are →
    - to encode a binary zero(space) the f_1 signal is passed to the output
    - to encode a binary one(mark, the f_2 signal is passed to the output



Example of FSK

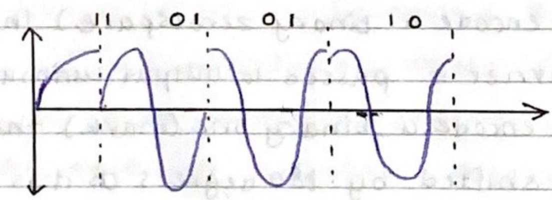
- Phase Shift Keying
  - ↳ Modulator can be transmitting input carrier signal as →
    - in phase without modification
    - phase shifted by radians or 180 degrees
  - ↳ Allows for one-bit encoding per signal element.
  - ↳ For encoding purposes, the rules are →
    - to encode a binary zero(space) the in-phase carrier is passed to output without modifications
    - to encode a binary one (mark) the carrier signal is shifted by 180 degrees as it is passed to output.



Example of PSK

- Quadrature PSK (Phase Shift Keying
  - ↳ similar to PSK except the modulator can transmit the input carrier signal ~~in~~ on 4 forms →
    - in phase - without modification
    - phase shifted in multiples of $1/2$ radians or 90°
  - ↳ Choosing this method improves channel capacity
  - ↳ Allows 2 bit encoding per signal elements
  - ↳ technique provides 4 different levels to be used for encoding data - incoming bit stream can be divided into 2 bit quantities with each 2 bit quantity represented by a single modification of the carrier signal
  - ↳ for encoding purposes, the rules are →
    - to encode 00, the previously modified carrier is passed to the output without further modification
    - to encode 01, the previously modified carrier is shifted by $(1/2)$ radians and passed to output
    - to encode 10, the previously modified carrier is shifted by $(2 \times 1/2)$ radians and passed to output
    - to encode 11, the previously modified carrier is shifted by $(3 \times 1/2)$ radians and passed to output

For example - Bit stream 11010110 →



! Full duplex communications means communicating in both directions simultaneously.
  - ↳ can be achieved because analogue signal can co-exist on a single transmission path - provided they have different frequencies.

- CODEC (used to generate a digital) is the device considered
- To encode analogue data onto a digital signal →
    - Convert analogue data into digital data
    - Encode the digital data onto a digital signal

↳ First step requires sampling because analogue data-signal has an infinite amount of data, and is not feasible to send all the analogue data.

- The encoding methods to consider are →
    - Pulse Code Modulation (PCM)
        → Sampling - Making signal measurements at discrete and equal intervals of time
        → Quantization - Constraining measured values to a limited set of amplitude values.
    - Analogue data signal can never be reproduced
    - PCM samples the amplitude of the signals at regular intervals and quatizes those samples into digital values.

↳ Example

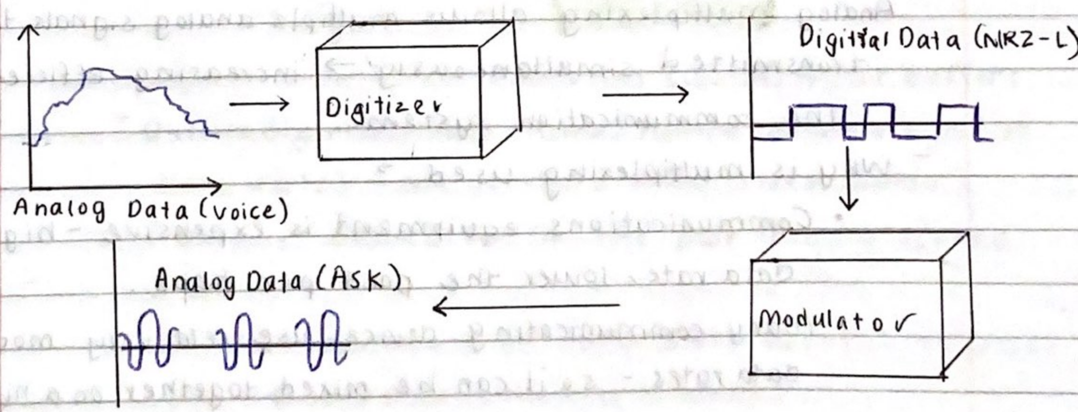
PCM is encoding voice data results in 8-bit samples

↳ this means each sample needs 8 bits to represent it

$D = B \times S$ b = bits per sample
S = sample rate

$D = 8 \times 8000$

$D = 64{,}000$ or 64KBps which is the data rate in Europe



- Delta Modulation (DM)
  - → This technique involves the use of a staircase function →
    - ↳ The analogue signal is approximated by a simple mathematical function
    - ↳ At each sampling interval a positive or negative quantization step is added to the output
    - ↳ Result is a single binary digit for each sample indicating a positive or negative slope in the original analogue signal.
  - → Error signal is encoded
  - → The parameters for this technique are →
    - Quantization step delta (δ)
      - large delta reduces slope overload noise
      - small delta reduces quantization noise
    - Sampling Rate
      - large rate reduces noise but increases data rate of output signal

- DM compared to PCM
  - DM is easier to implement
  - PCM has better Signal-to-Noise ratio.

Analogue Data/Analogue signals

- Analogue data can be used to modulate an analogue signal.
  - ↳ often used to obtain appropriate frequency for a particular transmission.
- Analog multiplexing allows multiple analog signals to be transmitted simultaneously → increasing efficiency of the communication system.

sharing of data comms facility

- Why is multiplexing used →
  - Communications equipment is expensive - higher the data rate, lower the cost per Kbps.
  - Many communicating devices use relatively modest data rates - so it can be mixed together on a higher speed system.

- Multiplexing examples
  - Cable networks such as TV, Broadband, Radio, etc
  - Telecommunications networks such as fibre, coaxial links, etc
- Types of multiplexing techniques -
  - Frequency-Division Multiplexing
    ↳ each analog signal is modulated onto a different carrier frequencies which are all ~~them~~ combined and transmitted over the same medium.
    combined to produce a composite analogue signal (also called baseband signal).
    ↳ the bandwidth of composite signal must be greater than the sum of bandwidths of input signals.
    ↳ guard band must be inserted between carrier frequencies to prevent overlap.
    ↓
    at the recieving end the carrier signals are demodulated and original analog signal is recovered.
  - Synchronous Time-Division Multiplexing
    ↳ portions of each input signal are interleaved in time (as opposed to frequency) onto the transmission medium
      ↳ incoming carrying signals can either be analogue (with encoded digital data) or digital.
      ↳ Interleaving can be at a bit level or in blocks of bytes
        ↳ determines the size of input buffers.
    ↳ Data is organised into frames (which contain a cycle of time slots) - one or more time slots within a frame is dedicated to one pair of data source devices
      ↳ combination of time slots across successive frames is called a channel

↳ System is synchronous because →
- time slots are pre-assigned to source devices
- they are transmitted regardless of whether the source devices are sending data.

↳ Frame synchronisation is required:
- achieved using a separate channel
- known as Added digit framing.

↳ TDM used to be part of public long haul telecommunications system.

Synchronous Transmission

Data Comms Techniques

- Two types of data transmission
  - Serial → one bit at a time (we focus on this)
  - Parallel → more than one bit at a time on several channels
    ↳ typically 8, 16 or 32 bits
- Data is typically transmitted one bit at a time over a channel
- A high degree of cooperation is required between devices
- The timing (rate, duration and spacing) must be identical for the transmitter and the receiver.
- To successfully receive the data bits the receiver device must sample an incoming bit stream once every bit interval -
  ↳ must know the duration of each bit
  ↳ for 1Mbps transmission, the bit duration is 1 millionth of a second.
- Timing is achieved on both sides using an internal electronic clock - we need to make sure these clocks are synchronised.
- We can achieve sychronisation as such →
  → Use separate clock link (not viable for computer-to-computer) as its too expensive.
  → Ignore potential problems and send very short bursts of data (asynchronous transmission).

→ Embed clocking pulses within the data signal ↗ synchronous transmission
this is more commonly used.

Asynchronous Transmission

- A method of serial data transmission where data is sent one byte (or character) at a time, without using a shared clock signal.
- Instead each character is accompanied with a start and stop bits - which define boundaries of data
- Advantages → simple and cheap
  → Typically used between keyboard and pc.
- Disadvantage → Overhead is typically 20% ex - 2 framing bits plus 8 data bits

Synchronous Transmission

- Here the data bits are transmitted in a large block of bits in a structure called frame.
  →The structure of frames is as follows →
  - Preamble Field or Opening Flag at the start of frame
  - Postamble Field or Closing Flag at the end of frame
  - Data and control information fields in middle
  - The format also depends on the data link protocol used.

Opening Flag	Control Fields	Variable-Length Data Field	Control Fields	Closing Flag

Data Link Control

- Layer of control logic that is required above the physical layer in each Source/Destination device is called Data Link Control.
  ↳ when used it can transform a basic transmission link into a fully functioning data communications channel.

Data Link Control Requirements

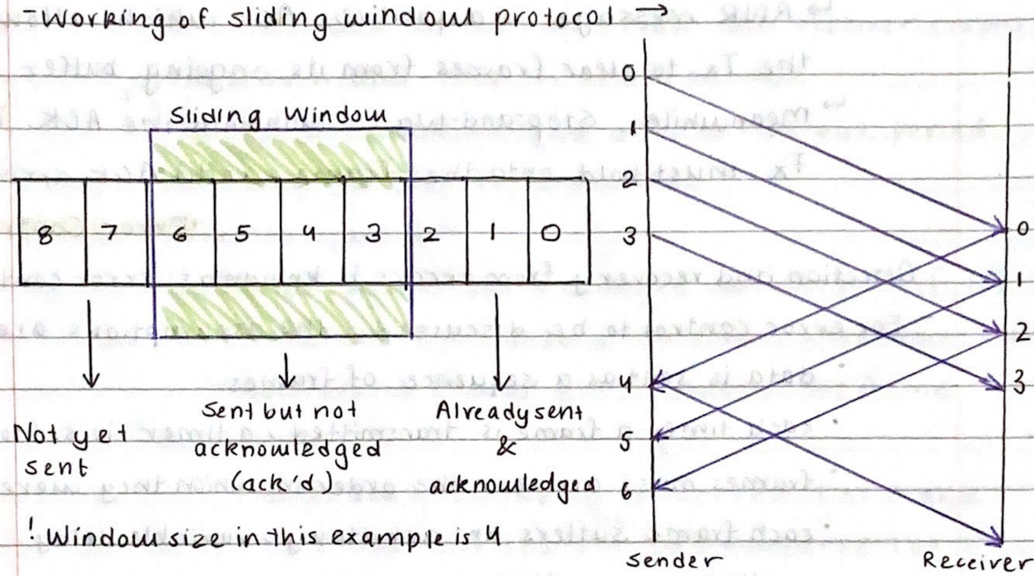
- The six basic requirements are →
  - Frame synchronisation - frames must be recognizable by the receiver
  - Flow control - The sender must not overload the receiver
  - Error control - Errors should be detectable by the receiver
  - Addressing - For a multipoint configuration, each station must be uniquely identifable
  - Control and Data on same link - Receiver must not have to wait for control information to arrive before it can process a frame
  - Link managgement - Procedures for established and reliquishing the link must be adhered to.

Flow Control

- Receiver and Sender stations each allocate a data buffer of a fixed size:
  - ↳ Data remains in the buffer until it has been processed by the Receiving station
    - ↳ Consequently the buffers can fill to capacity.
- Flow control enables the receiving station to indicate to the Sending station that its buffers are full.
- Flow control of techniques are as follows →
  - Stop-and-Wait Flow Control
    - ↳ The sending station transmits a frame -
      - The sending station must get an acknowledgement (an ACK) from the receiving station before transmitting the next frame.
      - The receiving station can control the flow of data by withholding ACKs.
    - ↳ Only allows for a single frame in either direction.
      - ↳ Half Duplex Communications

Sliding Window Flow Control

- Sending and receiver stations use an extended buffer size to hold extra frames.
  - ↳ Both stations maintain a list of frames sent or received.
- This technique allows for more efficient link utilization
  - ↳ the transmission link is effectively treated as a pipeline that can be filled with many frames in transit simultaneously.
- Techniques allows multiple frames to be in transit simultaneously in either direction - full duplex communication
- Working of sliding window protocol →



! Window size in this example is 4

- To impose flow control, the receiver can send a different control message →
  - ↳ Receiver Not Ready (RNR)
    - ↳ stems the flow from the sender
  - ↳ Receiver Ready (RR)
    - ↳ To resume flow
- ACKs can be included in outgoing data frames (in thier control fields)
  - ↳ this technique is called piggybacking - when a single frame can carry both Data and ACK's.

SW vs S-a-W flow control

- Sliding Windows are more efficient than Stop-and-Wait in relation to link Utilization
  - ↳ Stop-and-Wait can have only one frame in transit at any time - half duplex communications
  - ↳ Sliding Windows the link is treated like a pipeline that can be filled with multiple frames
    - ↳ which allows for full duplex communications.
- Sliding windows uses a special message RNR to impose flow control →
  - ↳ RNR message is a positive ACK which allows the Tx to clear frames from its ongoing buffer.
  - ↳ meanwhile, Stop-and-Wait withholds the ACK. The Tx must hold onto the frame until ACK arrives.

Error Control

- Detection and recovery from errors is known as error control
- For error control to be discussed, the assumptions are →
  - data is sent as a sequence of frames
  - each time a frame is transmitted, a timer is set to some value
  - frames must arrive in the order in which they were sent
  - each frame suffers an arbitrary, variable delay called propagation delay.
- Two types of errors can occur →
  - Lost frame / Lost ACK - Either a data frame or an ACK frame is lost in transit.
  - Damaged frame - Frame arrives but fails error detection check
- Error control has techniques that can be considered a tool-chest
- Provides the following elements →
  - Error detection
  - Positive ACK - Receiver sends positive ACKs to error free frames received

- Retransmission - Transmitter may retransmit a frame that has not been acknowudged after a time-out period.
- Negative ACK - Receiver can send negative ACK for out of sequence or damaged ~~sequence~~ frames that arrive
  - ↳ Transmitter may simply retransmit frames

- Error control techniques are called Automatic Repeat Request (ARQ).
- ARQ techniques →
  - Stop-and-Wait ARQ
    - An enchancement to the Stop-and-Wait Flow control
    - If the frame contains an error, the receiver simply discards it and does not return an ACK.
    - if Frame is not acknowledged after a time-out period the frame is just retransmitted.
    - ! Potential problem
      - ↳ ACK is sent but is damaged ~~but~~ in transit, the transmitter will resend the frame after time-out
        - ↳ Receiver will now get 2 copies of the frame
    - ! Solution
      - ↳ Frames are alternatively numbered 1 or 0 and ACKs are correspondingly also numbered 1 or 0.
  - Go-Back-N ARQ
    - An enchancement to the Sliding Window Flow Control
    - Errors (or non-errors) that can occur →
      - Successful transmission -
        - ↳ Receiver returns a positive ACK with the number of the next frame expected
        - ↳ ACK can be also piggybacked on Data frame
        - ↳ Transmitter continues to send data frames up to the agreed window size.
      - Lost Data frame or ACK frame -

- There are two responses depending on type of error →
  - Lost frames / Damaged frames
    - ↳ treated the same
    - ↳ Receiver sends a (REJ) message with the number of next frame expected
  - Lost ACKs
    - ↳ The timer helps us if no ACKs are received
    - ↳ If the timer for a frame has expired or not the transmitter can respond →
      - * if timer has not expired - it can send more frames up to the error condition
      - * if timer has expired the transmitter stops transmitting data frames, spends a special RR message and a poll bit (like a control signal) ← called a command frame
      - * receiver must respond with a RR message and number of next frame

- Selective-Reject ARQ
  - Very similar to the Go-Back-N technique with the exception that the only frames retransmitted are →
    - Transmitted frames where timer has expired
    - Transmitted frames that were lost or damaged
      - ↳ Receiver uses slightly negative ACK called Selective Reject (SREJ) message
  - Considered more efficient than Go-Back-N as it minimises the amount of retransmitted frames.
  - ! However technique is more complex as Receiver station has to →
    - Store a frame after damaged frame has been rejected
    - Has the re-sequence re-transmitted frames as they arrive out-of-sequence
    - Requires more complex logic on both stations.

Sample Protocol - HDLC

High Level Data Link Control

- Widely used and forms the basis for ~~an~~ many data link control protocol
- Protocol has 3 types of stations →
  - Primary station - Controls the operation of the link through the use of commands
  - Secondary station - Operates under the control of primary station - it responds to commands
  - Combined station - Can send commands AND responses
- Synchronous transmission is used - transmission is in frames
- HDLC Frame format →

Flag	Address	Control	Information	FCS	Flag
8 bits	8 extendable	8 or 16	variable	16 or 32	8

Flag Fields

- All active stations scan incoming bit streams
  - ↳ initially to determine 'start of a frame'
  - ↳ continues to scan to find the 'end of a frame'
- Same flag pattern can be used for start and end of two consecutive frames
- Flag pattern (01111110) must not occur inside frame
- Prevented by bit stuffing
  - ↳ extra '0' bit is inserted after 5 consecutive '1' bits
  - ↳ Example -

Before → 111111111111011111101111110

After → 1111101111110110111110101111101 0

Address Field

- Used to identify the stations - relevant on a multi-point link
- Usually 8 bits long but is extendable

Control Field

- There are 3 different types of frames with their own control fields →
  - Information (I) frames carry Data. Can also carry piggybacked frame sequence numbers for Flow and Error Control
  - Supervisory (S) frames carry flow and error control data when not piggybacked
  - Unnumbered (U) frames provide link control functions such as set-up and disconnect.

Information Field

- Present in I-frames, which is where data is stored
- Length is variable upto some predefined system specific limit
  - ↳ must be in multiples of 8 bits

FCS Field

- Used in error detection - calculated using all the bits within the frame excluding flags
- Normally a 16-bit CRC (previous error detection technique) is used.

HDLC Commands / Responses

Frame Type	Name	Command / Response	Description
Information (I)	Info	C/R	Exchange user data
Supervisory (S)	Receive Ready	C/R	Positive ack, ready to receive i-frame
Supervisory (S)	Receive NOT Ready (RNR)	C/R	Positive ack, not ready to receive i-frame
Supervisory (S)	Reject (REJ)	C/R	Negative ack, go back N
Supervisory (S)	Selective Reject (SREJ)	C/R	Negative ack, selective reject
Unnumbered (U)	SNRM	C	Set mode
-	SARM	C	Set mode
-	SABM	C	Set mode
-	DISC	C	Terminate logical link
-	UA	R	Acknowledge U-frame command
-	DM	R	Station is logically disconnected
-	UI	C/R	Used to exchange control info

... and many more

HDLC Operations

- All HDLC interactions follow 3 distinct phases of operations →
  - Phase 1 : Initalisation
    - Link is set up prior to communications.
    - Either station can be set up by sending one of 6 set mode commands - most common SABM
    - Receiving station responds with an unnumbered acknowledgement (UA) to accept or Disconnect mode (DM) to reject.
    - Only 'U' frames are used during this phase
  - Phase 2 : Data Transfer
    - This is where data is transferred using I-frames
    - Each I-frame contains 2 sequence numbers
      - ↳ One relates to the outgoing frame
      - ↳ Other is a piggybacked ACK for a frame received from the other side of the link
      - ↳ When piggybacking is not used - S-frames are used
      - ↳ First frame transmitted is always numbered 0.
  - Phase 3: Disconnect
    - Either station can initiate disconnect phase
    - Acheived using U-frame containing DISC message
    - Remote station must respond with a U-frame containing a VA message.