CSE 3231
Computer Networks

Chapter 3
The Data Link Layer
part 1 - Framing

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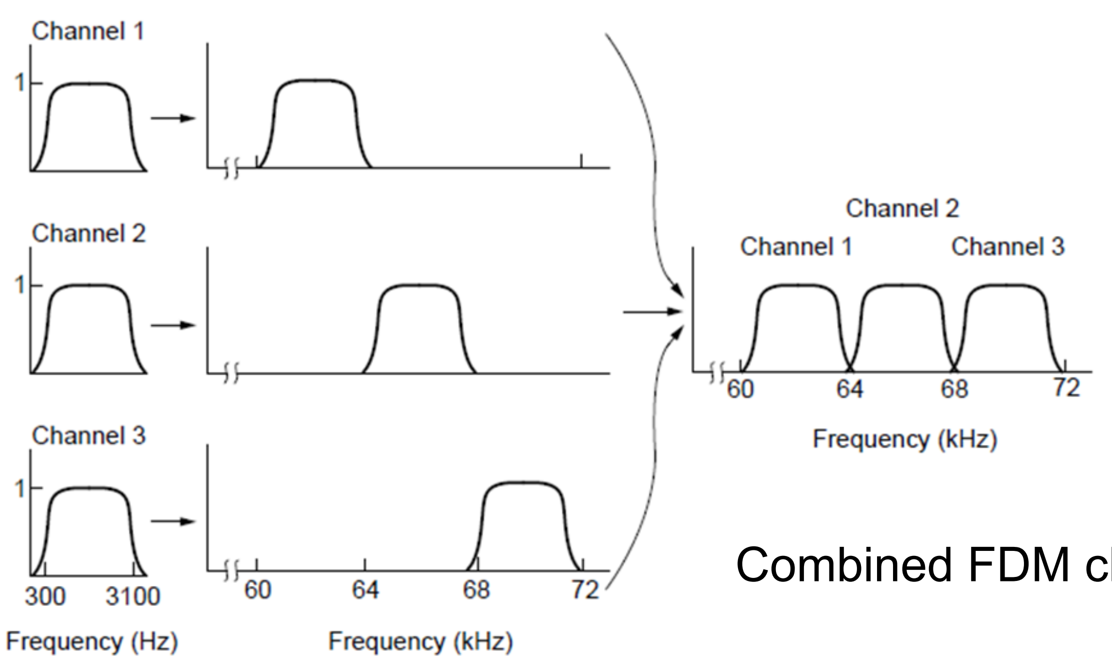
Frequency Division Multiplexing (FDM)

Frequency Division Multiplexing shares the network bandwidth by assigning users to different frequency channels and transmitting them simultaneously

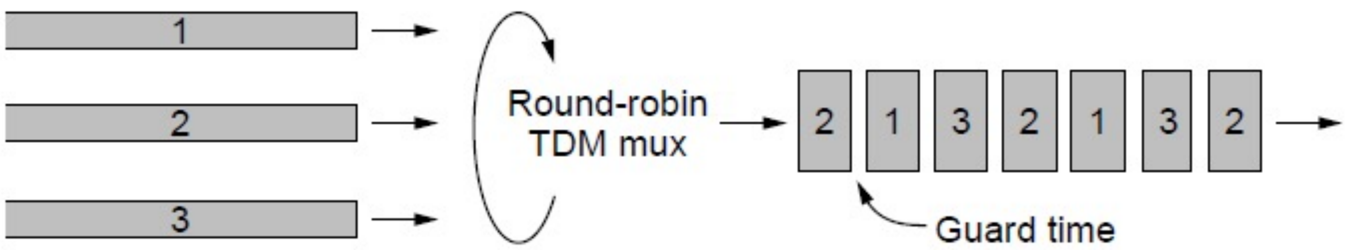


Combined FDM channel

Time Division Multiplexing (TDM)

Time division multiplexing allows sharing a channel based on *time slicing*:

- Inputs are selected on a fixed schedule
  - Data to be sent is stored in queues and chosen in a round-robin order
  - A small “guard time” separates each user
- Widely used in telephone / cellular systems



Problems with TDM & FDM

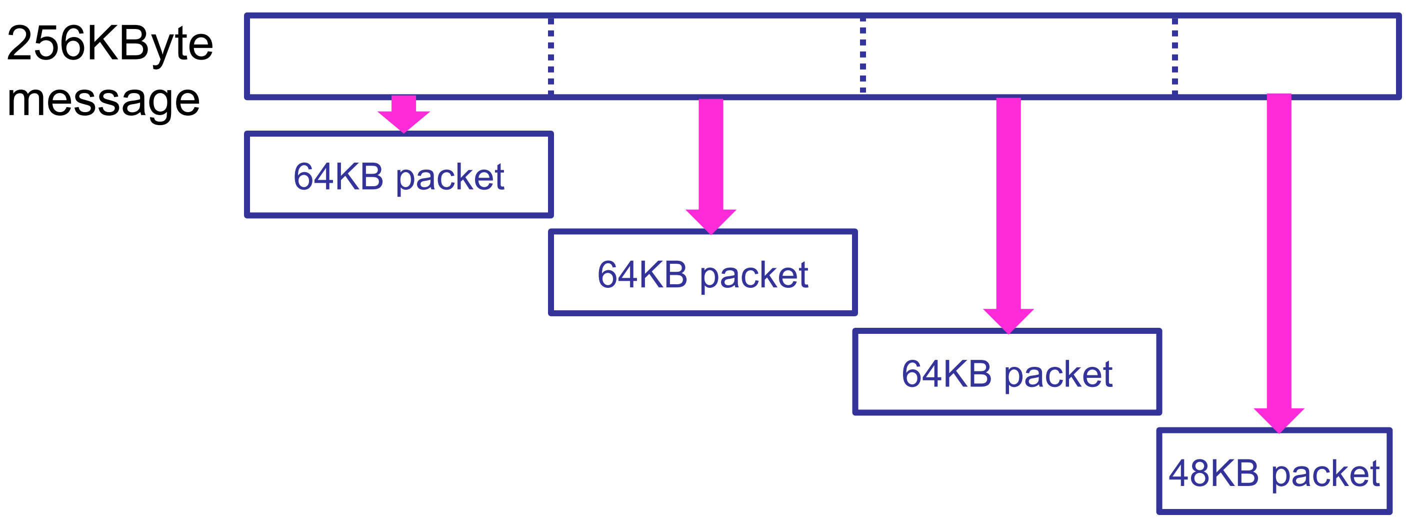
- As more users are added to the network:
  - Time-division results in longer waiting until a user's next time slot
  - Frequency-division is limited to a maximum number of frequencies over one medium
- How to solve this?
  - Statistical Multiplexing – users only transmit *when they need to* and the length of a time slot is limited to a fixed size, called a *packet*

Statistical Multiplexing

- If nodes do not need to transmit data, they wait and the time slot or frequency they would have used is given to the next node
  - If only ½ of the nodes need to transmit, this effectively gives the others twice the bandwith
- However, there has to be some way to determine when a node wants to transmit or a slight delay to give them time to start
  - even so, the overall benefits are significant

Sending Data in Packets

- *Packet* - a fixed-size block of bits taken from a larger-sized message
  - assume maximum packet size is 64KBytes, but message is 240kBytes, message must be subdivided into packets, each ≤ 64KBytes

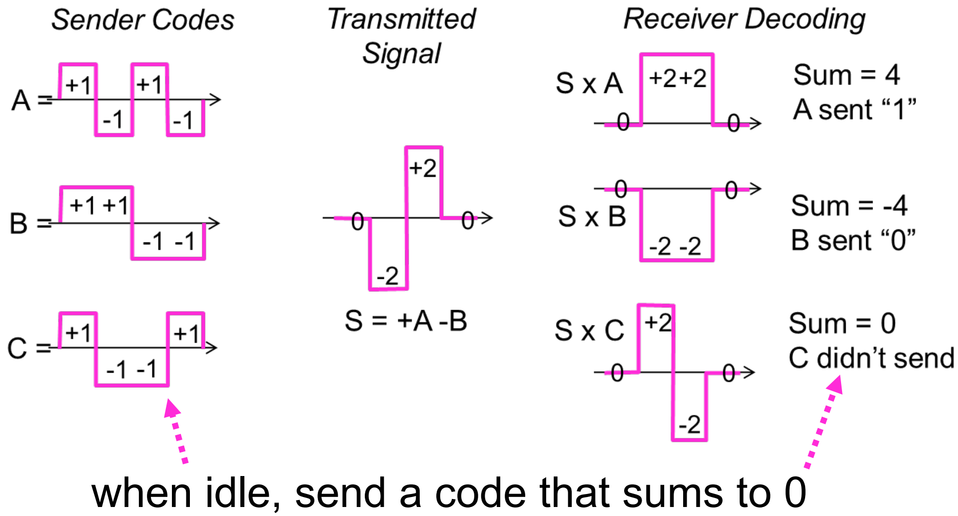


Code Division Multiple Access (CDMA)

CDMA does not use separate frequencies or time slices, it assigns each user a unique set of patterns or "codes" to represent 0's and 1's

– The codes are designed so that they can be sent at the same time without colliding with each other

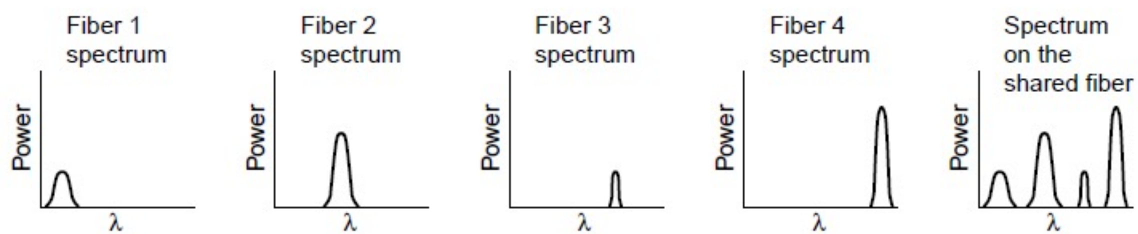
This is a form of *Spread-Spectrum* transmission and is used in satellite, cell phone and cable networks



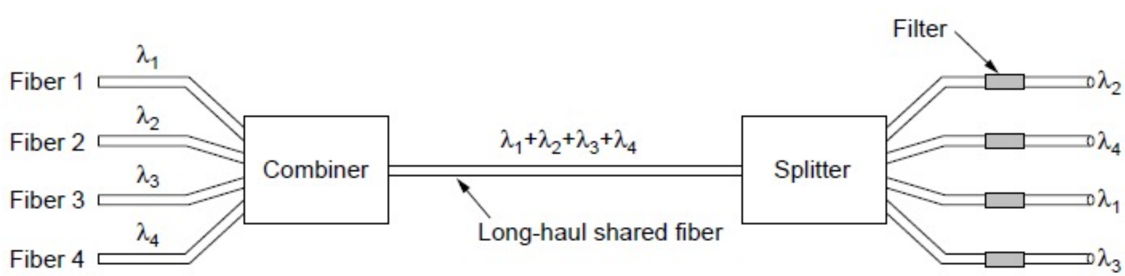
Trunks and Multiplexing

Wavelength Division Multiplexing (WDM) another type of FDM, is used to carry many signals on one fiber optic cable

- TeraBit (trillion-bit) data rates are possible



a number of non-overlapping frequencies are merged to increase the total data rate

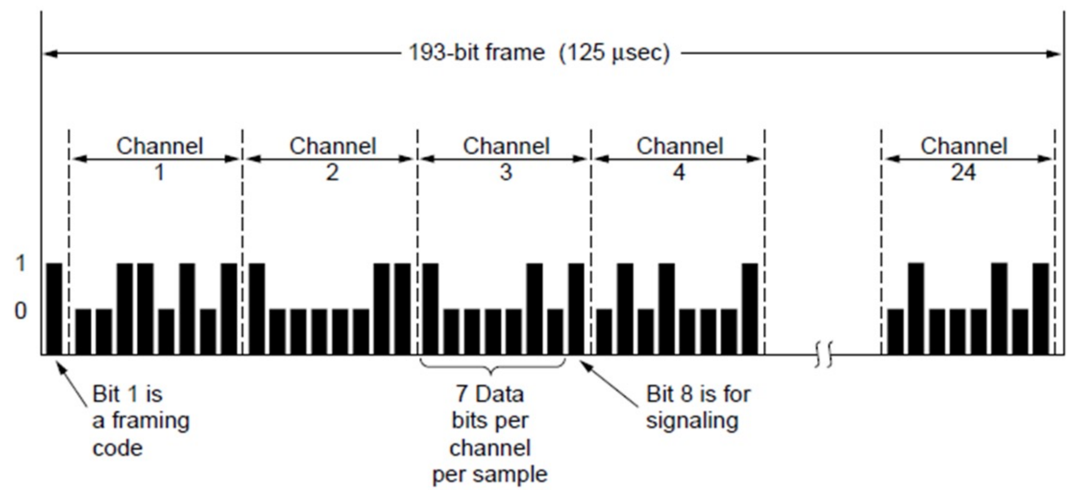


Trunks and Multiplexing

The Public Switched Telephone Network (PSTN) uses TDM to carry voice calls

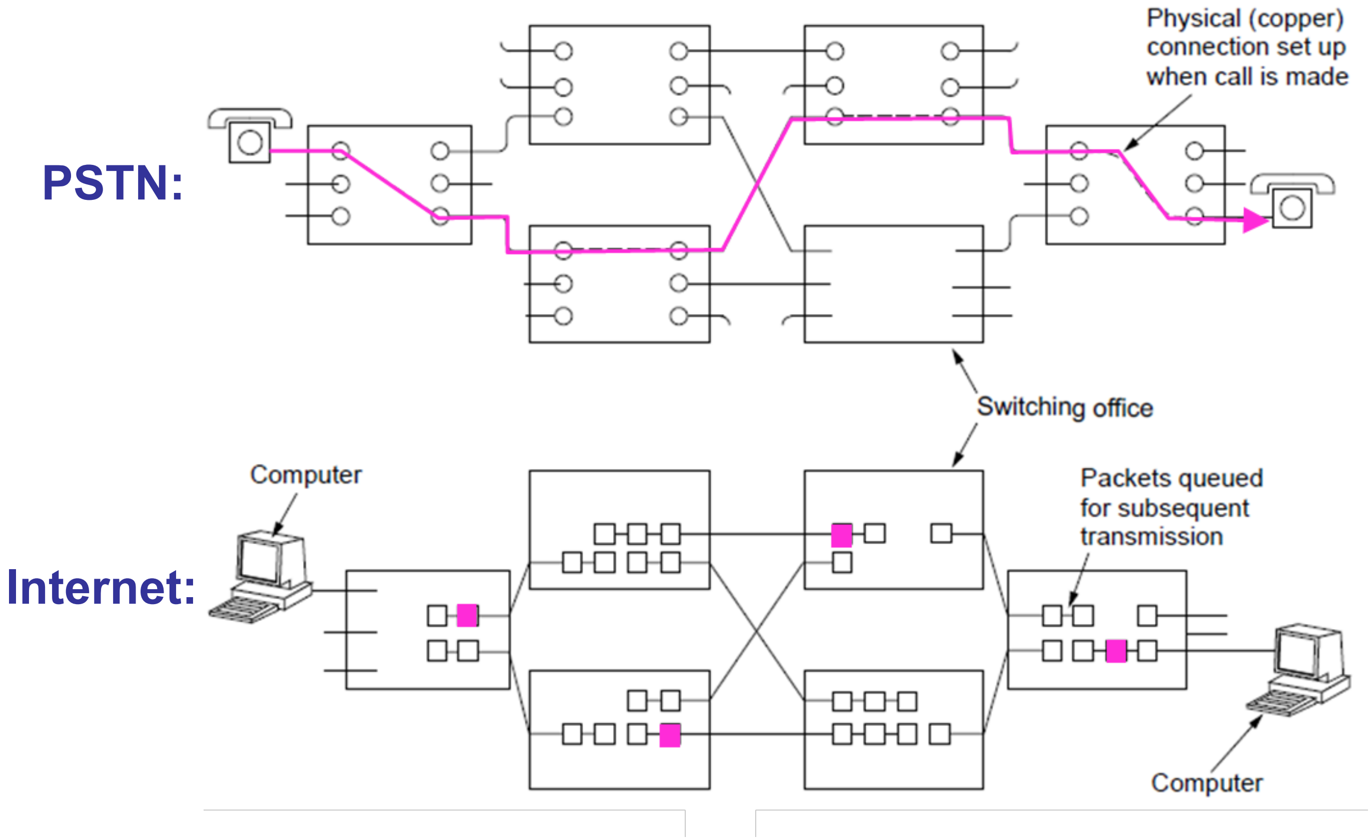
– During a call, an 8-bit PCM sample is taken every 125 μs (64 kbps) of the connection, i.e. 8,000/sec

- 24 call channels are grouped into a traditional T1 carrier
- Sampling of each call occurs every 125 μs and gives a total of 1.544 Mbps of data

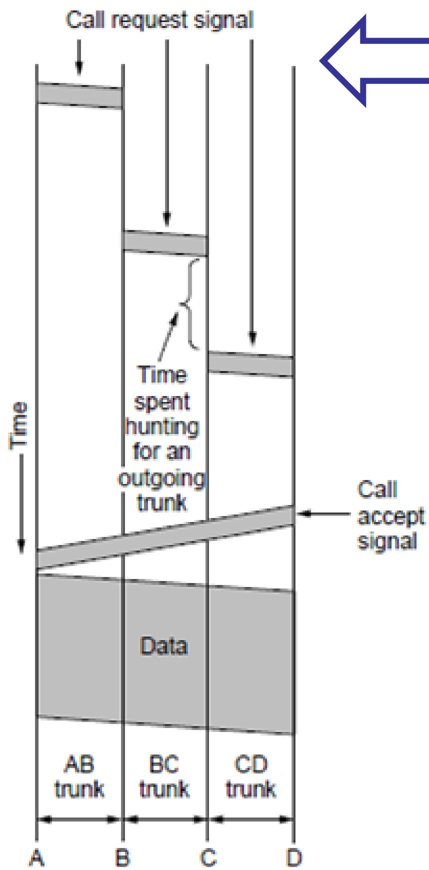


Switching

The Public Switched Telephone Network uses circuit switching; Internet uses packet switching

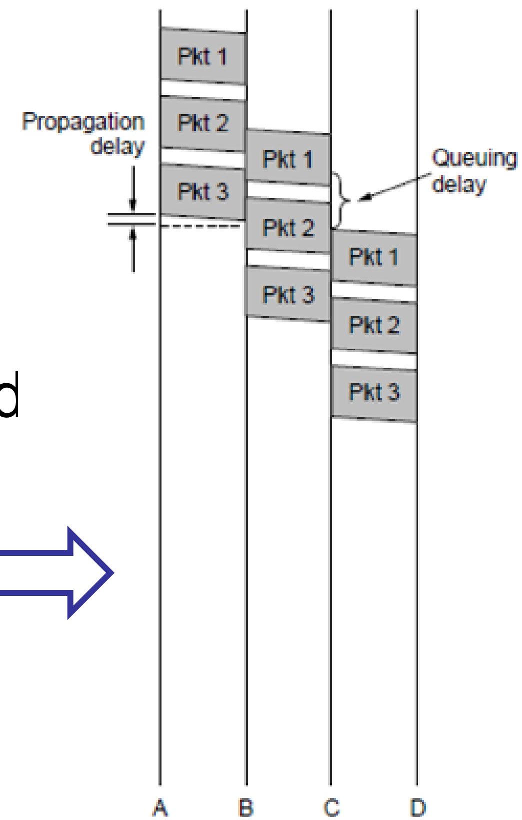


Switching



Circuits

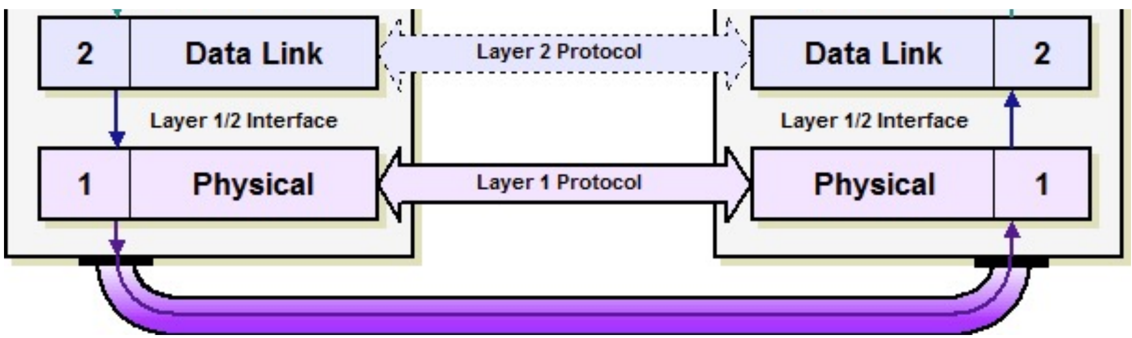
- Circuit switching requires call setup (connection) before data is transmitted
  - Also, teardown is needed afterwards (not shown)
- Packet switching treats messages independently
  - No setup, but queuing delay occurs at routers



Packets

Description of Layers

- Physical Layer
  - Handles the transmission of raw bits over a communication link – wire, radio, optical, etc.
- Data Link Layer
  - Collects a stream of bits into a *frame*
  - Network adaptor and device driver in the OS implement the protocol in this layer
  - Frames are delivered using the Physical Layer



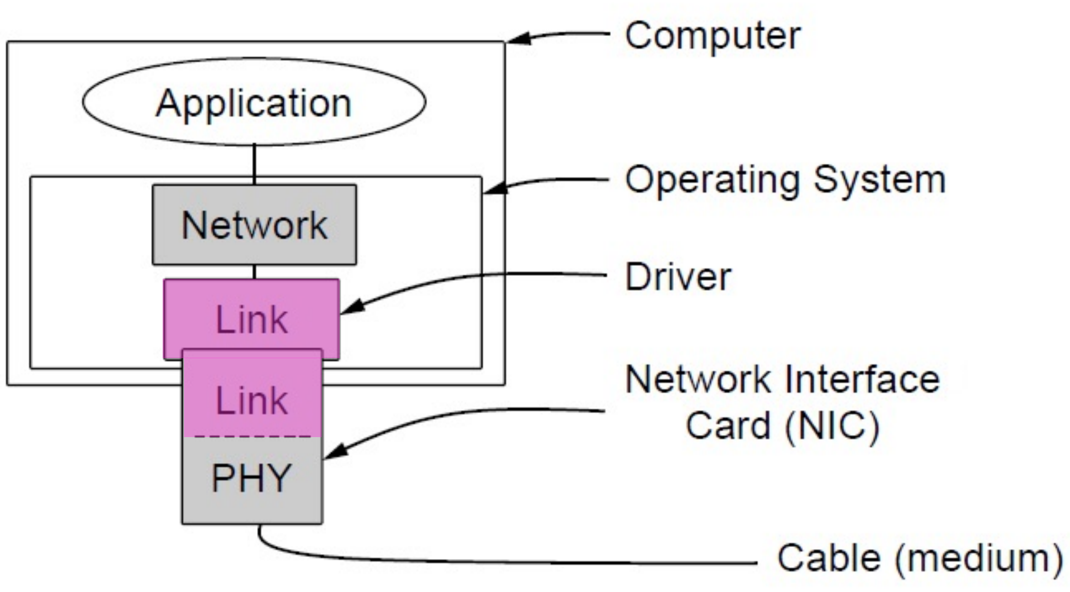
Control access to the medium

Transmit data across a medium

Link layer environment

Commonly implemented in a combination of the Network Interface Card (NIC) and OS drivers

The network layer (IP) is normally in OS software



Data Link Layer Components

1. Provides services to the Network Layer for the delivery of frames over the physical link
   - hiding delivery details from the network layer
   - constructing/processing frames
   - detecting and handling transmission errors
   - regulating the flow of data from node to node
2. Supports sharing of the specific type of media
   - some aspects relate to the particular type of media
   - detecting or avoiding collisions over that media
   - this component is covered in the next chapter

Parts of the Data Link Layer

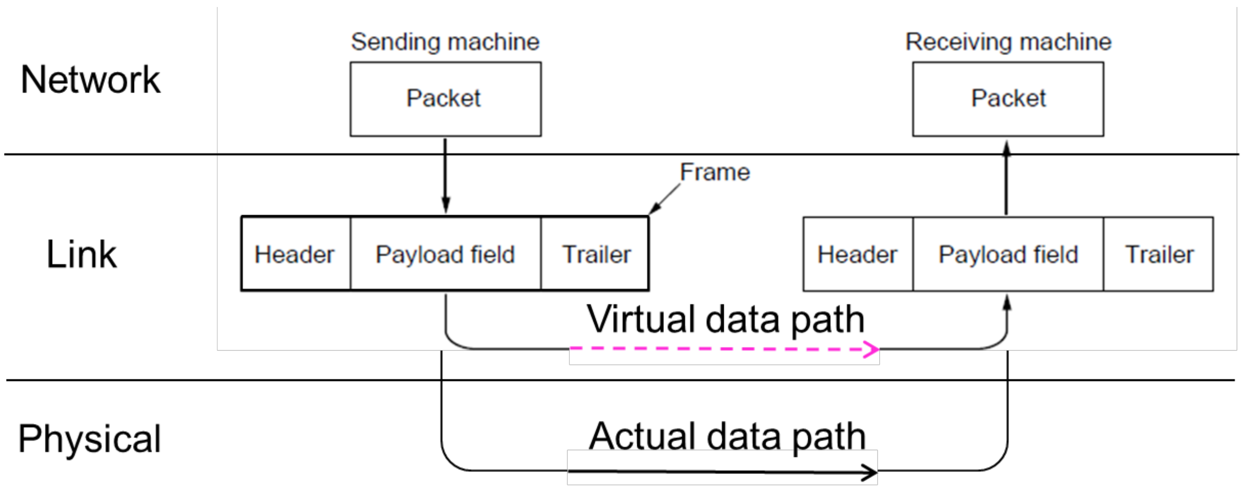
Two sublayers handle the different functions

- Media Access Control (MAC) - controls access to the transmission medium
  - converts binary data into *frames* which include a header, a payload (packet data) and a trailer
  - delivers frames to the physical layer for encoding
- Logical Link Control - provides flow control, acknowledgements and notification of errors
  - interfaces with the Network layer
  - this will be covered in the *next lecture*

Frames

The Data Link layer

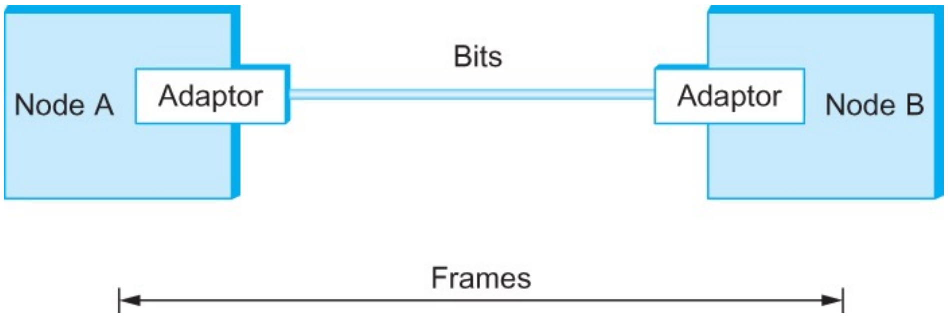
- accepts packets from the network layer
- encapsulates them into *frames*
- sends them to the receiver using the physical layer
- reception of the packet reverses the process



Why Framing?

Physical-layer network connections normally specify a *maximum block size* to support the reliable transmission of data

- These blocks of data (called *frames*) are exchanged between the nodes
- Network adaptors at each node create, transmit and receive these frames



Framing

- When node A prepares to transmit a frame to node B, it assembles the data and headers in memory and signals its adaptor to transmit the frame from its location in memory. This results in a sequence of bits being sent over the link.
- The adaptor on node B receives the sequence of bits and deposits them into B’s memory.
- The primary task faced by the receiver is to *determine where the frame begins and ends*
  - this is the purpose of *framing*

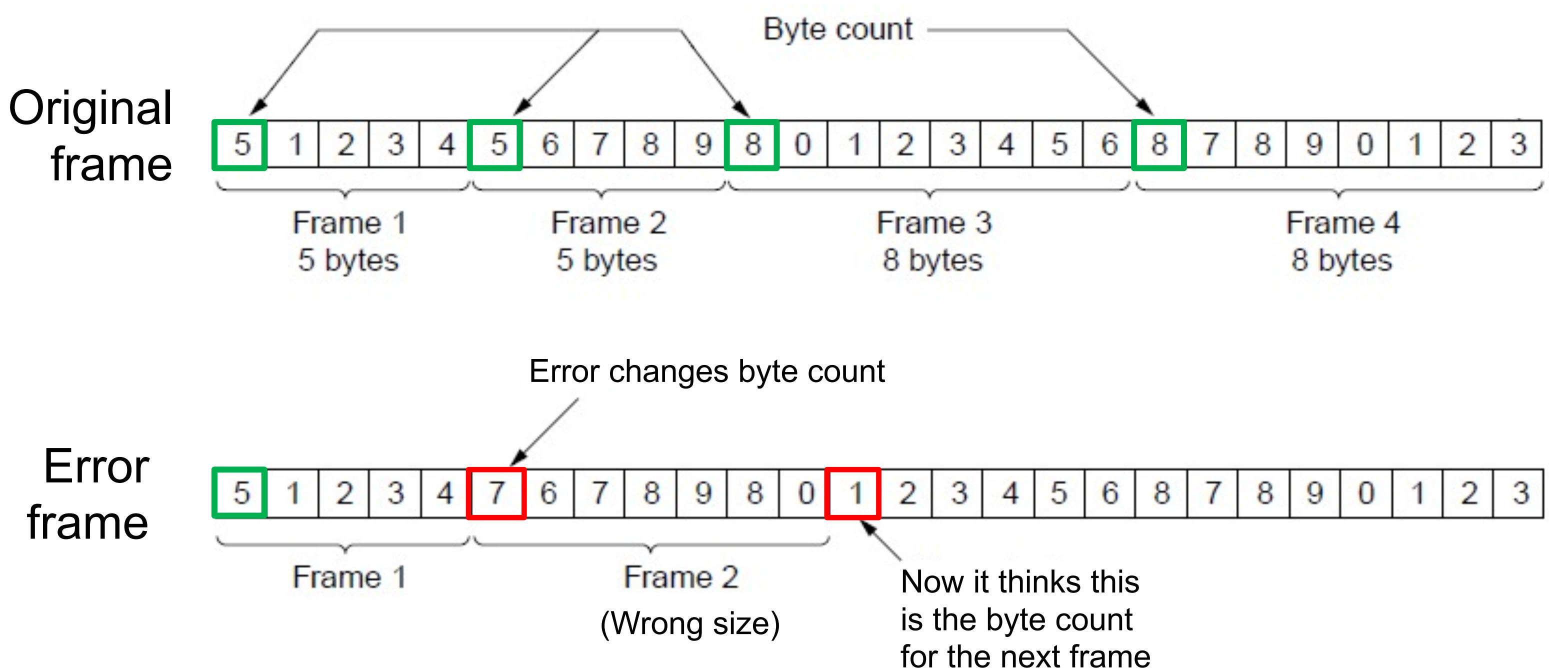
Types of Framing

- There are several ways to mark the length of a Data Link frame:
  - Byte Count - include the size of the frame in the frame's data
  - Byte-Oriented - use special codes to indicate where the frame begins and ends
  - Fixed-size - the format of the frame is preset; the end is always *X* bytes from the beginning

Framing – Byte Count

Each frame begins with a count of the number of bytes that it contains

- Simple, but difficult to resynchronize after an error



Framing

- Another technique: view each frame as a collection of characters and use special codes
- Referred to as Byte-oriented Protocols.
- Often used with Mainframe computers (1960's)
  - BISYNC (Binary Synchronous Communication) Protocol
    - Developed by IBM (late 1960)
  - DDCMP (Digital Data Communication Protocol)
    - Used in DECNet
- More recent protocol: PPP (Point-to-Point)
  - Used for DSL connections, etc.

Framing Example

- BISYNC – uses special character codes
  - Beginning of a frame is denoted by sending a special SYN (synchronize) character twice
  - Data is contained between special sentinel characters STX (start of text) and ETX (end of text)
  - Other special codes (these can be found in an ASCII table):
    - SOH : Start of Header
    - DLE : Data Link Escape - allows use of special codes within data section of the frame
    - EOT: End Of Transmission

Decimal - Binary - Octal - Hex – ASCII Conversion Chart

Decimal	Binary	Octal	Hex	ASCII	Decimal	Binary	Octal	Hex	ASCII	Decimal	Binary	Octal	Hex	ASCII	Decimal	Binary	Octal	Hex	ASCII
0	00000000	000	00	NUL	32	00100000	040	20	SP	64	01000000	100	40	@	96	01100000	140	60	`
1	00000001	001	01	SOH	33	00100001	041	21	!	65	01000001	101	41	A	97	01100001	141	61	a
2	00000010	002	02	STX	34	00100010	042	22	"	66	01000010	102	42	B	98	01100010	142	62	b
3	00000011	003	03	ETX	35	00100011	043	23	#	67	01000011	103	43	C	99	01100011	143	63	c
4	00000100	004	04	EOT	36	00100100	044	24	$	68	01000100	104	44	D	100	01100100	144	64	d
5	00000101	005	05	ENQ	37	00100101	045	25	%	69	01000101	105	45	E	101	01100101	145	65	e
6	00000110	006	06	ACK	38	00100110	046	26	&	70	01000110	106	46	F	102	01100110	146	66	f
7	00000111	007	07	BEL	39	00100111	047	27	'	71	01000111	107	47	G	103	01100111	147	67	g
8	00001000	010	08	BS	40	00101000	050	28	(	72	01001000	110	48	H	104	01101000	150	68	h
9	00001001	011	09	HT	41	00101001	051	29	)	73	01001001	111	49	I	105	01101001	151	69	j
10	00001010	012	0A	LF	42	00101010	052	2A	*	74	01001010	112	4A	J	106	01101010	152	6A	j
11	00001011	013	0B	VT	43	00101011	053	2B	+	75	01001011	113	4B	K	107	01101011	153	6B	k
12	00001100	014	0C	FF	44	00101100	054	2C	,	76	01001100	114	4C	L	108	01101100	154	6C	l
13	00001101	015	0D	CR	45	00101101	055	2D	-	77	01001101	115	4D	M	109	01101101	155	6D	m
14	00001110	016	0E	SO	46	00101110	056	2E	.	78	01001110	116	4E	N	110	01101110	156	6E	n
15	00001111	017	0F	SI	47	00101111	057	2F	/	79	01001111	117	4F	O	111	01101111	157	6F	o
16	00010000	020	10	DLE	48	00110000	060	30	0	80	01010000	120	50	P	112	01110000	160	70	p
17	00010001	021	11	DC1	49	00110001	061	31	1	81	01010001	121	51	Q	113	01110001	161	71	q
18	00010010	022	12	DC2	50	00110010	062	32	2	82	01010010	122	52	R	114	01110010	162	72	r
19	00010011	023	13	DC3	51	00110011	063	33	3	83	01010011	123	53	S	115	01110011	163	73	s
20	00010100	024	14	DC4	52	00110100	064	34	4	84	01010100	124	54	T	116	01110100	164	74	t
21	00010101	025	15	NAK	53	00110101	065	35	5	85	01010101	125	55	U	117	01110101	165	75	u
22	00010110	026	16	SYN	54	00110110	066	36	6	86	01010110	126	56	V	118	01110110	166	76	v
23	00010111	027	17	ETB	55	00110111	067	37	7	87	01010111	127	57	W	119	01110111	167	77	w
24	00011000	030	18	CAN	56	00111000	070	38	8	88	01011000	130	58	X	120	01111000	170	78	x
25	00011001	031	19	EM	57	00111001	071	39	9	89	01011001	131	59	Y	121	01111001	171	79	y
26	00011010	032	1A	SUB	58	00111010	072	3A	:	90	01011010	132	5A	Z	122	01111010	172	7A	z
27	00011011	033	1B	ESC	59	00111011	073	3B	;	91	01011011	133	5B	[	123	01111011	173	7B	{
28	00011100	034	1C	FS	60	00111100	074	3C	<	92	01011100	134	5C	\	124	01111100	174	7C	|
29	00011101	035	1D	GS	61	00111101	075	3D	=	93	01011101	135	5D	]	125	01111101	175	7D	}
30	00011110	036	1E	RS	62	00111110	076	3E	>	94	01011110	136	5E	^	126	01111110	176	7E	~
31	00011111	037	1F	US	63	00111111	077	3F	?	95	01011111	137	5F	_	127	01111111	177	7F	DEL

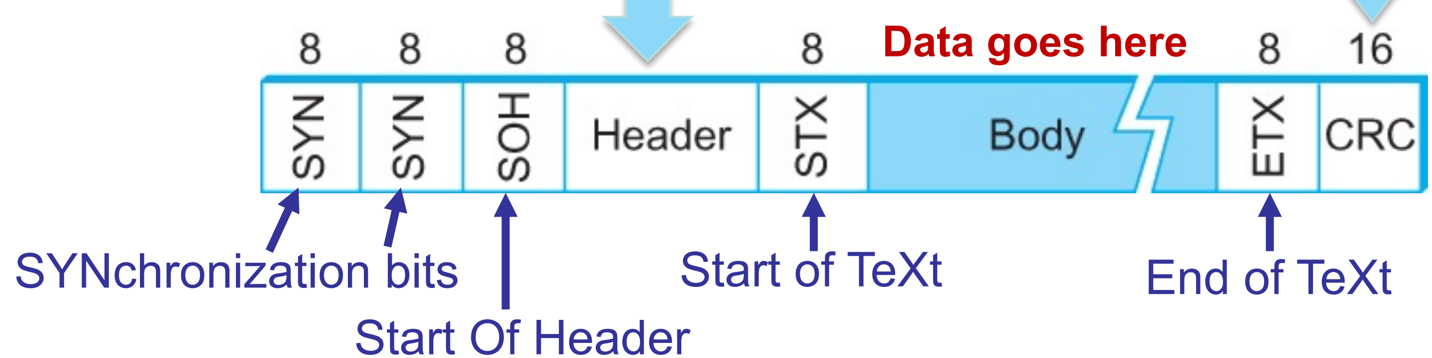
Framing Example

- The ASCII character set includes specific codes for these sentinel characters:
  - SYN (00010110)
  - SOH (00000001)
  - STX (00000010)
  - ETX (00000011)
  - DLE (00010000), etc.
- Since these are different from the ASCII codes for alphabetical, numeric and punctuation, they can easily be identified in the packets

BISYNC Framing Example

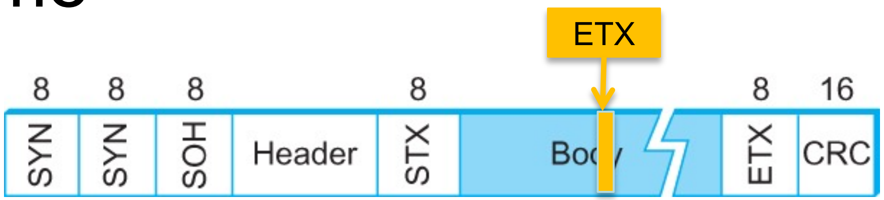
The CRC (Cyclic Redundancy Check) enables the detection of transmission errors. Later, we will see some of the algorithms used for error detection

The header contains a number of fields that are used to maintain link-level delivery reliability



Framing

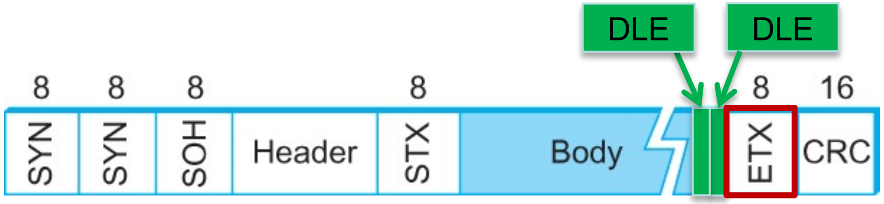
- What if one of the sentinel bit patterns appears in the body of the data?
  - If it is ASCII text, that won't happen because they aren't normal alphabetic characters
  - But, if the body of the frame is binary data, any value can appear and the ETX bit pattern (`00000011`) might appear as valid data in the body of the frame



Framing

- How can we determine that the real ETX is not part of the body of data in the frame?
  - We can solve this by "*escaping*" the special characters, an approach called "*character stuffing*"
    - this is similar to the way we escape **\n** in printf
  - A Data Link Escape (DLE) character is inserted in front of the ETX command at the end of the body to indicate that this ETX is not part of the data
  - However, that DLE must also be escaped as well

The DLE, DLE will be ignored and the ETX will mark the end of the body



Framing Error

- Could the bytes DLE DLE ETX appear as valid data in the frame?

  `00010000 00010000 00000011`

  - Yes, but the probability of DLE DLE ETX appearing together is very low, and it is even more unlikely that the DLE DLE ETX combination would be followed by a valid CRC value for the preceding data, so the frame would be rejected anyway

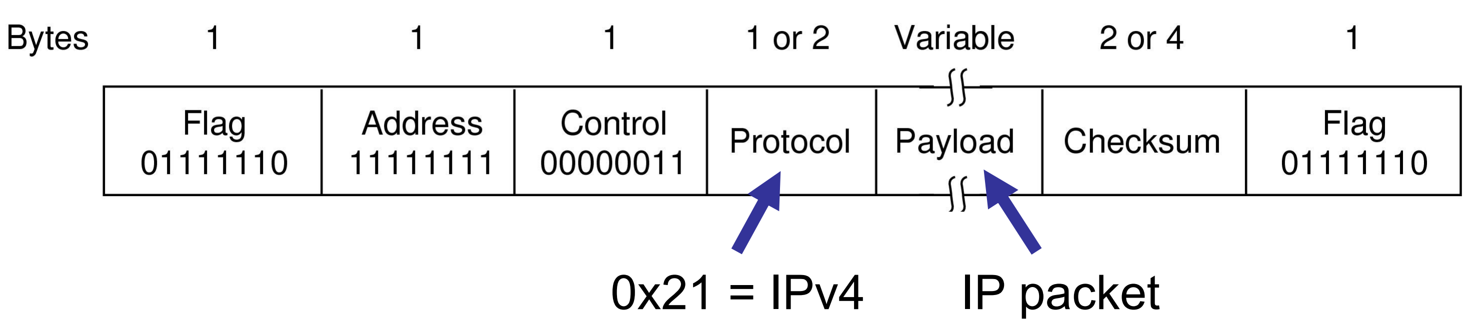
Example Data Link Protocols

- There are many Data Link Layer protocols and the following are common examples
  - PPP (Point-to-Point Protocol)
  - ADSL (Asymmetric Digital Subscriber Line)
  - HDLC (High-level Data Link Control)
- In some cases, two protocols may be combined where one protocol provides the framing and another handles the flow control or interfaces to the physical layer

PPP

PPP (Point-to-Point Protocol) is a general method for delivering packets across links

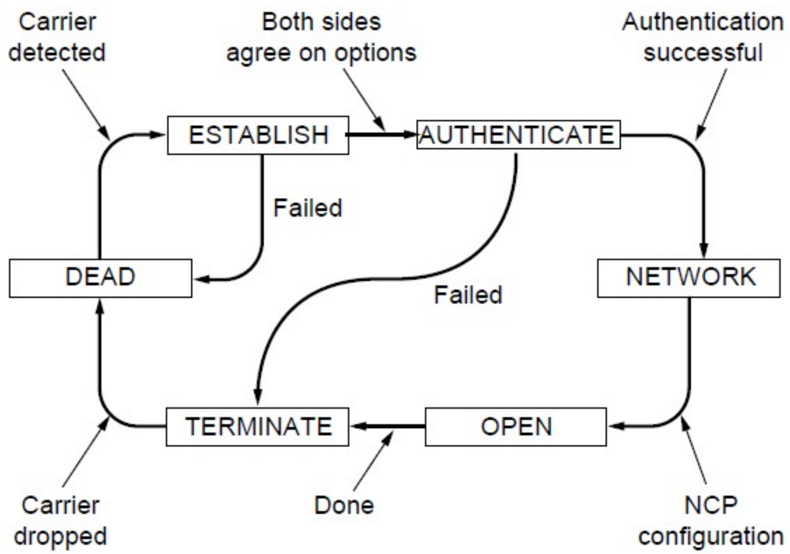
- Framing uses a flag byte (0x7E) and byte stuffing
- Payload size is variable, but default is 1500 bytes
- A connectionless unacknowledged service is used to carry IP packets
- Errors are detected with a CRC-32 checksum



PPP

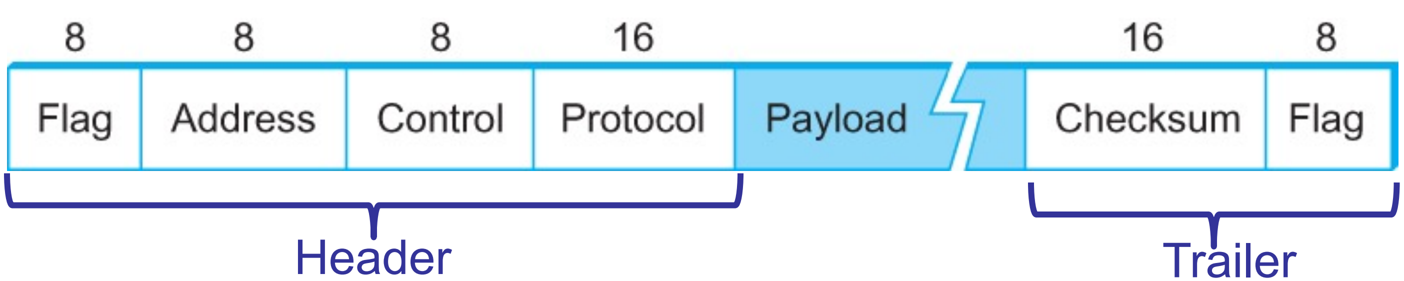
A Link Control Protocol configures and controls the PPP connection

- PPP can work with SONET, ADSL and Ethernet
- The Network Control Protocol (NCP) configures different Network Layer services



Framing Example

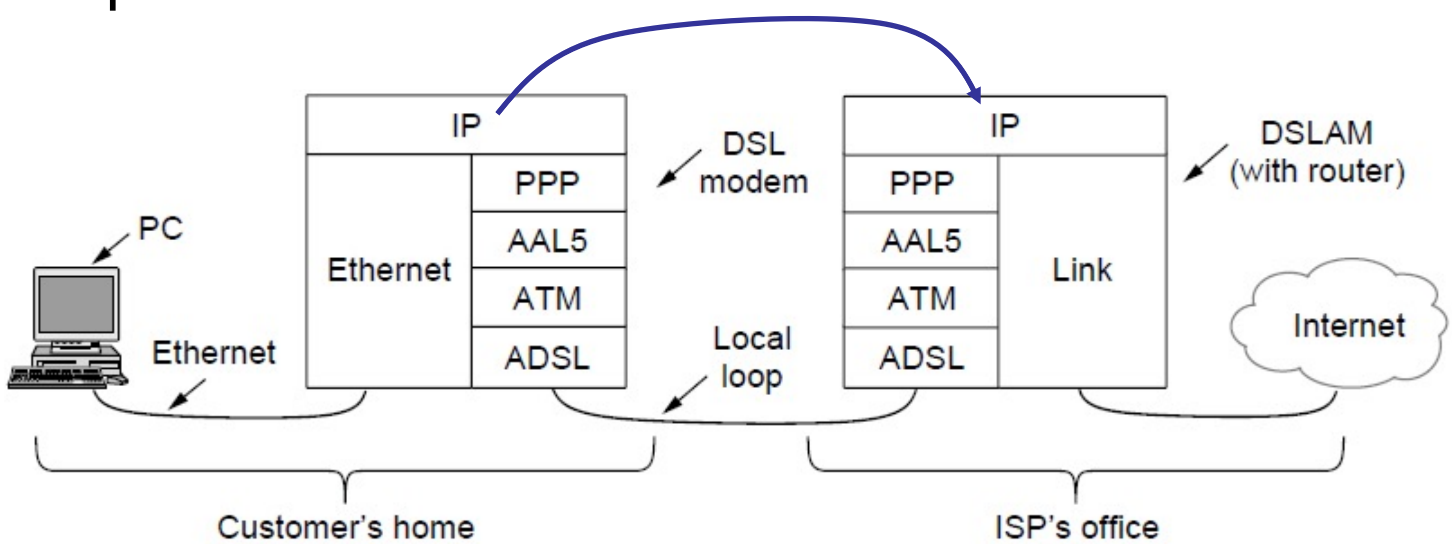
- PPP (Point-To-Point Protocol) also uses sentinel characters and has to escape them in a similar way, but with a different format
  - Special character called the "Flag" byte **01111110** used as both Start-Of-Text and End-Of-Text
  - Address & control fields: usually default values
  - Payload Size: negotiated (up to 1500 bytes)
  - Checksum : 2 or 4 bytes for error detection



ADSL

ADSL is widely used for broadband Internet over local loops to home users

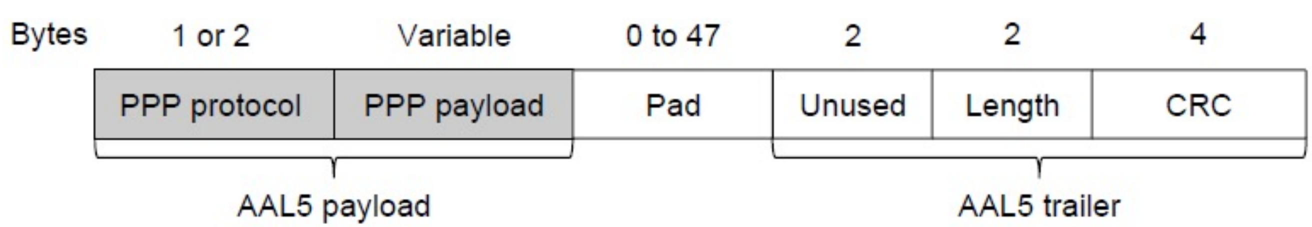
- ADSL runs between a customer's modem and the ISP's DSLAM (normally over telephone lines)
- IP packets are sent over PPP and AAL5/ATM



ADSL

ADSL consists of PPP data transmitted in AAL5 frames over ATM (Asynchronous Transfer Mode) cells:

- ATM has a link layer that uses short, fixed-size cells (53 bytes); each cell has a virtual circuit identifier
- AAL5 is a format to send packets over ATM
  - AAL5 frame is divided into 48 byte pieces, each of which goes into one ATM cell with 5 header bytes
- PPP frame is converted to a AAL5 frame (PPPoA)
  - PPPoA is PPP over ATM



Framing

- Bit-oriented Protocol
  - HDLC : High-level Data Link Control
    - Frame is viewed as a sequence of bits, not fields
    - Beginning and Ending bit sequence (also as idle bits)

      0 1 1 1 1 1 1 0
    - Since this sequence might also be in the data, extra bits are injected to create a unique sequence
      - (packet length may depend on the contents of the data)

HDLC Frame Format

Framing

- HDLC Protocol – uses "*bit stuffing*"
  - It is possible to send the Ending Sequence as data: 01111110 = decimal 126 = ASCII **~**
    - When the sender transmits five consecutive 1's in the body of the message and the next bit to send is also a **1**, it sees that it is about to send the ending sequence (01111110)
    - The sender 'knows' it isn't actually the end, so it will insert a 0 before transmitting the next **1** bit (called "*bit stuffing*")
    - changes 01111110 into 011111010 (using 9 bits)

Framing

- HDLC Protocol – uses "*bit stuffing*"
  - On the receiving side
    - If it gets 5 consecutive 1's, it looks at the next bit

if a **0** : it was stuffed after five 1's, so discard the **0**

if a **1** : this should be the Ending Sequence

Then, it looks at the bit after that:

If a **0** (01111110) → it was the Ending Sequence, OK

If a **1** (01111111) → Error, discard the whole frame

(There should never be more than 6 bits in a row)

If it was an error, the receiver would wait for the next 01111110, which marks the beginning of the next frame for it to receive

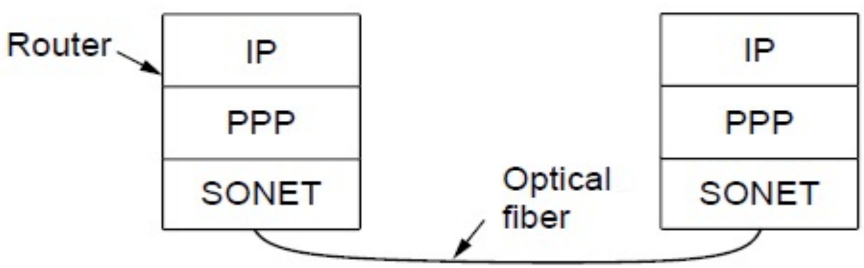
Clock-based Framing

- Used by the Synchronous Optical Network (SONET) standard
  - First introduced by Bell Communications Research
  - Jointly addresses the framing and the encoding problems in one frame format
  - Does not use bit-stuffing, so the payload length on the frame does not depend on the data being transmitted
  - The lowest speed SONET Link (STS-1, 51.84 Mbps) is the basis for the faster data rates as well
  - SONET can the multiplex multiple low bandwidth channels into a higher-bandwidth channel.

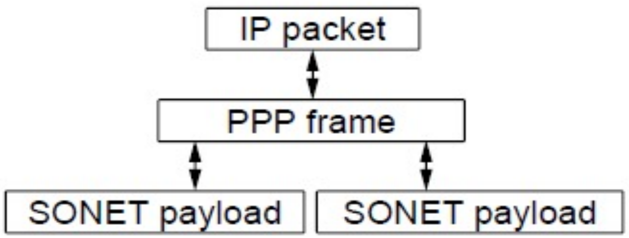
Packet over SONET

Packet over SONET is the method used to carry IP packets over SONET optical fiber links

- SONET handles flow control and frame delivery over fiber optic links
- PPP (Point-to-Point Protocol) provides framing



Protocol stacks

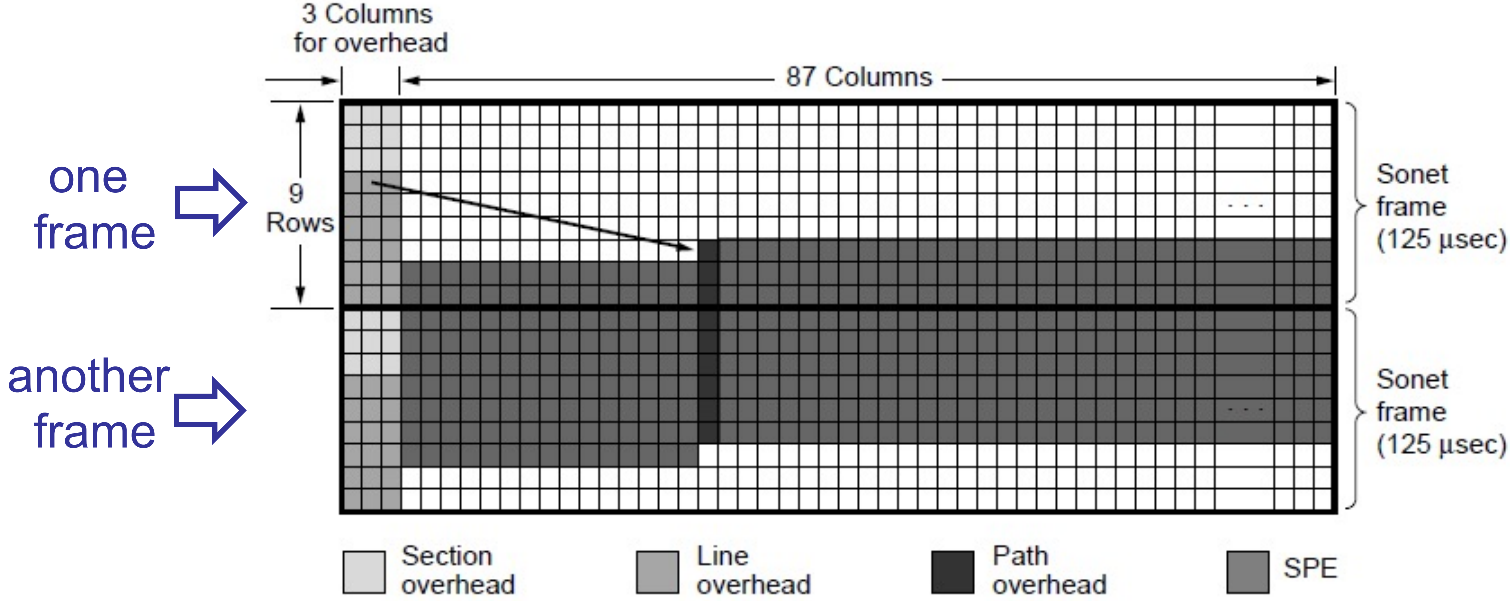


PPP frames may be split over SONET payloads

Trunks and Multiplexing

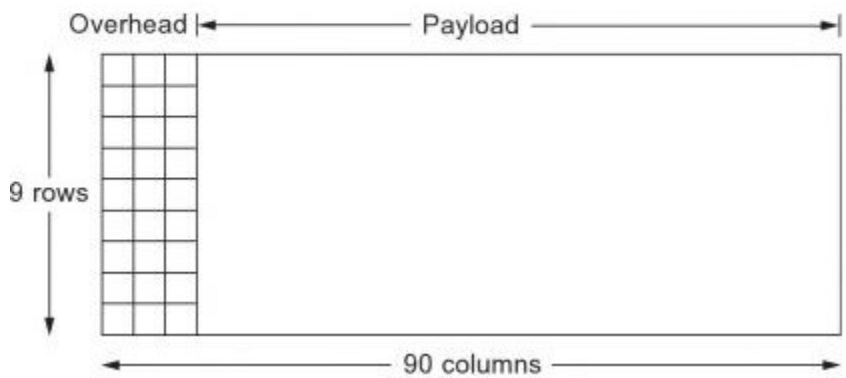
SONET (Synchronous Optical NETwork) is the world standard for digital signals on fiber optic

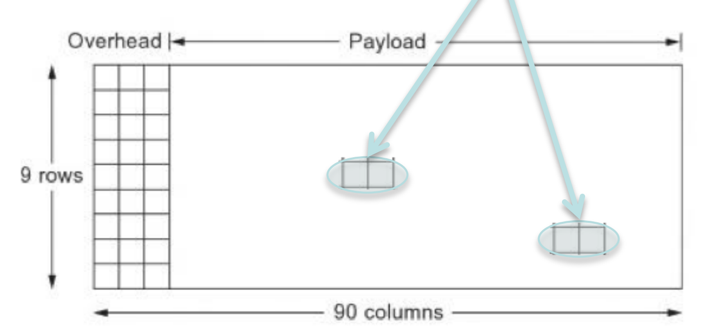
– Keeps 125 μs sample time, but base frame is 810 bytes (giving 52Mbps as a basic rate)



SONET frame format: 810 bytes per frame, sampled every 125 μs

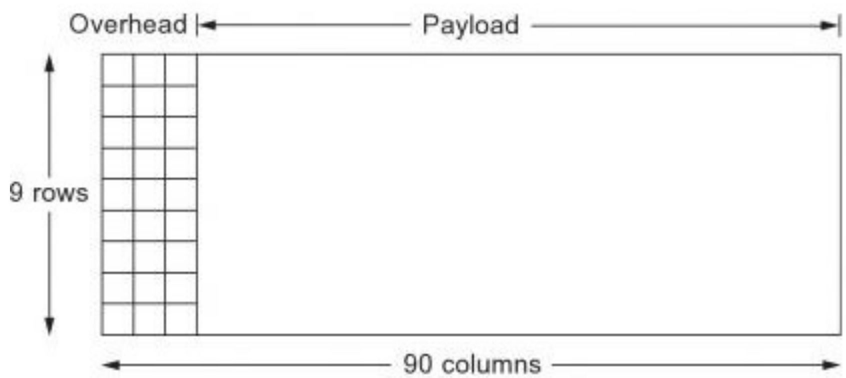
SONET STS-1 Frame





- Each frame is exactly the same size (810 bytes) and is organized as 9 rows of 90 bytes, each row starts with a special bit pattern in the first 2 bytes that is used for synchronization and counts the bytes after that pattern
  - If it finds the special pattern in the middle of a row, it knows that it is just part of the data and ignores it
- This ensures that the receiver can verify that it is in sync with the sender after every 90 bytes

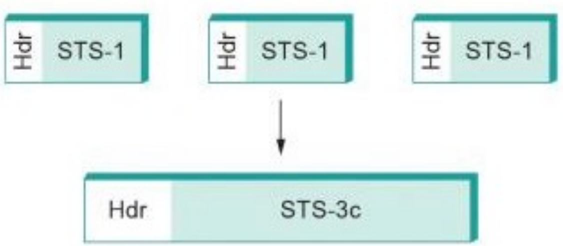
SONET STS-1 Frame



- SONET frames are encoded using NRZ
  - 1 is represented by a high amplitude, 0 by a low amplitude
- To further mitigate the clock recovery and baseline wander issues, the payload bytes are XOR'd much like in Manchester encoding, but not with a clock pulse
  - Instead, it uses a 127-bit pattern that is XOR'd with the data. That sequence of bits contains frequent changes from 0 to 1 and 1 to 0, to increase the likelihood of transitions in the result

Multiplexing STS-1 Frames

- SONET supports combining multiple base frames into larger frames to produce higher data rates
  - Ranging from 51.84 Mbps (STS-1) to 2488.32 Mbps (STS-48)
  - All rates are integer multiples of STS-1
  - For example, the STS-3 frame is 2430 bytes long, containing exactly 3 STS-1 frames (810 bytes each)
    - When combining STS-1 frames, the bytes are interleaved.
    - That is, the sequence includes the first byte of each STS-1 frame, followed by the second byte of each frame, and so on.



Trunks and Multiplexing

SONET supports a wide range of data rates, from 50 Mbps (STS-1) to 40 Gbps (STS-768) by modulating multiple basic rate signals.

SONET		SDH	Data rate (Mbps)		
Electrical	**Optical**	**Optical**	**Gross**	**SPE**	**User**
STS-1	OC-1		51.84	50.112	49.536
STS-3	OC-3	STM-1	155.52	150.336	148.608
STS-12	OC-12	STM-4	622.08	601.344	594.432
STS-48	OC-48	STM-16	2488.32	2405.376	2377.728
STS-192	OC-192	STM-64	9953.28	9621.504	9510.912
STS-768	OC-768	STM-256	39813.12	38486.016	38043.648

SONET/SDH rate hierarchy