Lectures 13 -15
Connections, Protocols, Link and Flow Control, LANs

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COMPSCI 314 S2C 2011

Assignment 2

- Due September 23 - start lab work *soon*
    - worth 5% of the final grade
- Understand the basic concepts of protocol layers and encapsulation by practical observation in the CS lab.
- Read and understand the tutorial document (16 pages) linked as "support material" at http://www.cs.auckland.ac.nz/courses/compsci314s2c/assignments/
- Learn to use the packet capture tools provided.
- Capture data for each part of the assignment, and analyse the results to answer the questions.
    - don't forget to include captured data in your PDF file

Background for Assignment 2

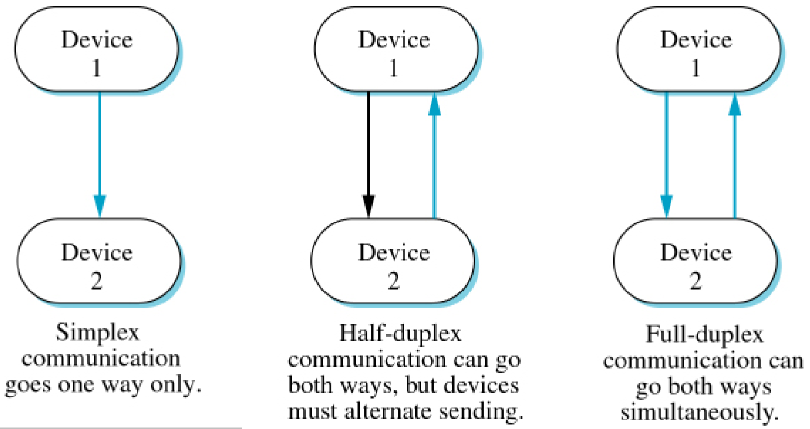
- Revise the material about TCP/IP from CompSci 215, or look ahead in Shay Chapters 9, 10 and 11.
- Packets include a sequence of *headers* corresponding to protocol layers.
- If we can inspect the packets, we can see and understand the headers.
- The CS lab machines have some tools for 314 students to allow capture and inspection of your packets.
    - capture packets to and from your IP address only, for privacy reasons

Tools installed on CS lab Windows

- wincap - a simple library supporting the windump command line utility.
- wireshark - a packet capture tool with a GUI.
- Using the tutorial, try out some packet captures like the examples given.
- Then you should be ready to start the assignment.

Transmission Modes - getting bits down a wire (Shay 4.3)

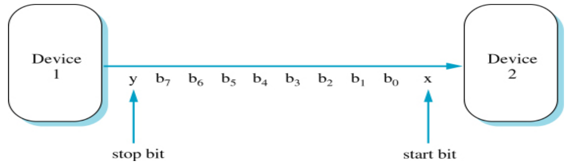
- Parallel (many wires) or Serial (one wire)
- Direction-related



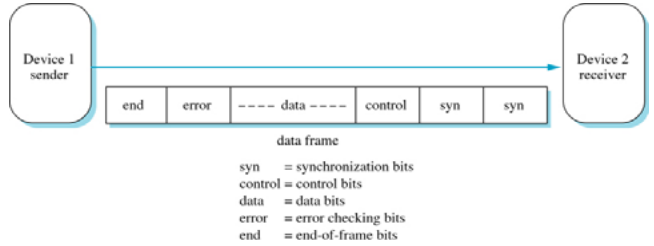
Diagrams from Shay are used throughout the lecture slides, without further acknowledgement.

Transmission Modes

- Time-related
  - asynchronous: may start/stop at any time



  - synchronous: uses a continuous clock



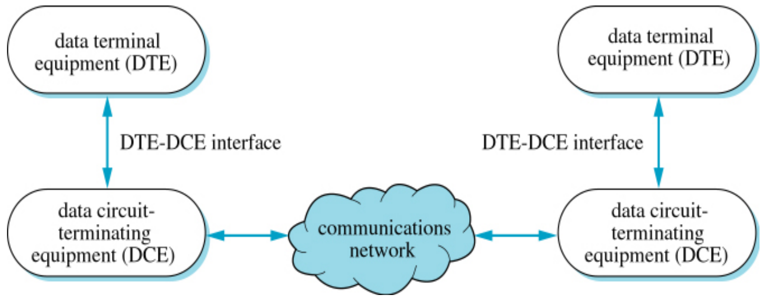
  - isochronous: inserts gaps to match transmission rates

Interface Standards (Shay 4.4)

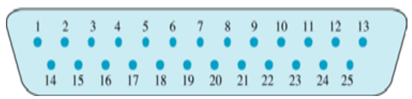
- There are lots of 'standard' interfaces for connecting devices together
- Shay has good descriptions of:
  - EIA-232 (RS-232) ← *we only look at this one, as a simple example, even though it's old.*
  - USB
  - IEEE 1394 (Firewire)
  - X.21

RS-232 Serial Interface

- Connects DTE (computer) to DCE (modem)

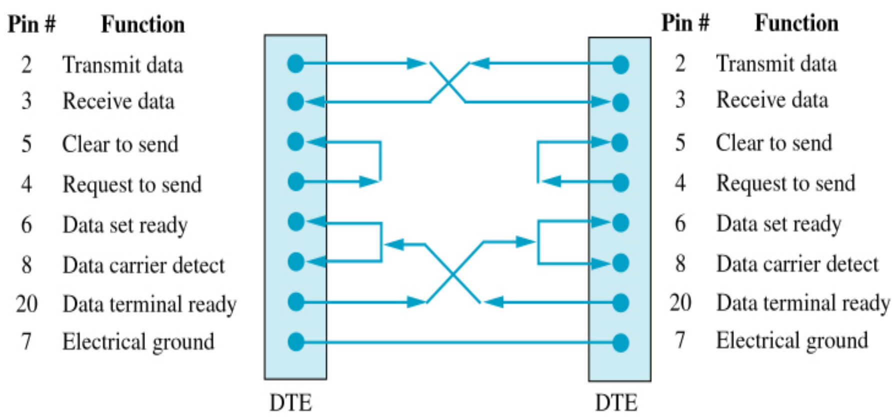


- 25-pin connector, we normally use only 9



RS-232 Serial Interface

- *Null Modem* for connecting two DTEs



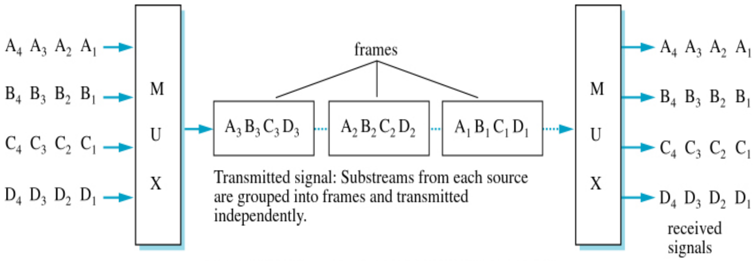
- *Not shown here:* pin 22 = Ring Indicator, pin 1 = Protective Earth

Multiplexing (Shay 4.5)

- Carrying several different connections over a common link.
  - Multiplexing makes one cable do the work of several separate cables.
- Useful because long distance cables are expensive and need to be shared.
  - Even within a building, you don't want a cable for every user back to a single central point.
- There are several methods of multiplexing.

Multiplexing (2): several bit streams, one channel

- Time-Division Multiplexing(TDM)



Signal sources: A_i, B_i, C_i, and D_i represent bit streams.

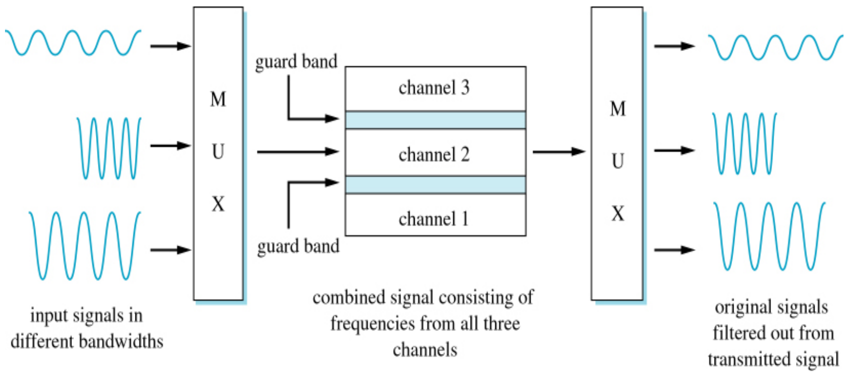
- A, B, C, D take regular turns
  - If a stream has nothing to send, its time slot is wasted.

Multiplexing (3): several bit streams, one channel

- Statistical Multiplexing
  - Similar to TDM, but doesn't use fixed time slots
  - If A has more to send than B, it will use more of the available time, and the timing will not be regular.
  - If a stream has nothing to send, another stream can use the channel.
  - Receiver must be able to identify incoming frames since there is no fixed time sequence.
  - Design must make sure that all bit streams get a fair share when the load is heavy.

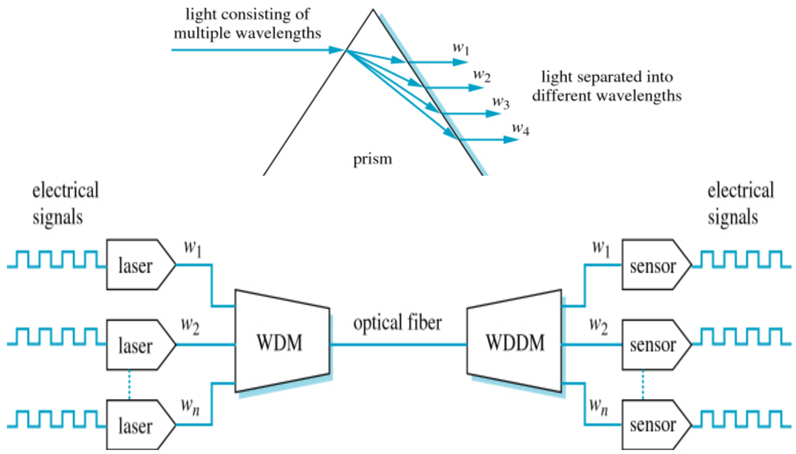
Multiplexing (4): radio-frequency signals

- Remember that each RF signal can carry a data stream as modulation



Multiplexing (5): optical (lightwave) signals

- Wave-Division (WDM):



Protocols

- A network protocol is a set of rules that defines how devices talk to each other.
  - It's an algorithm with two* separate participants.
  - They'd better obey the rules; otherwise communication will fail.
- Many examples of protocols around us, e.g. traffic rules (Road Code), 'phone conversations
- How can we be sure that a protocol is *correct?*
  - works properly
  - will never suddenly 'freeze'

******or possibly more than two*

Flow Control (Shay 8.1)

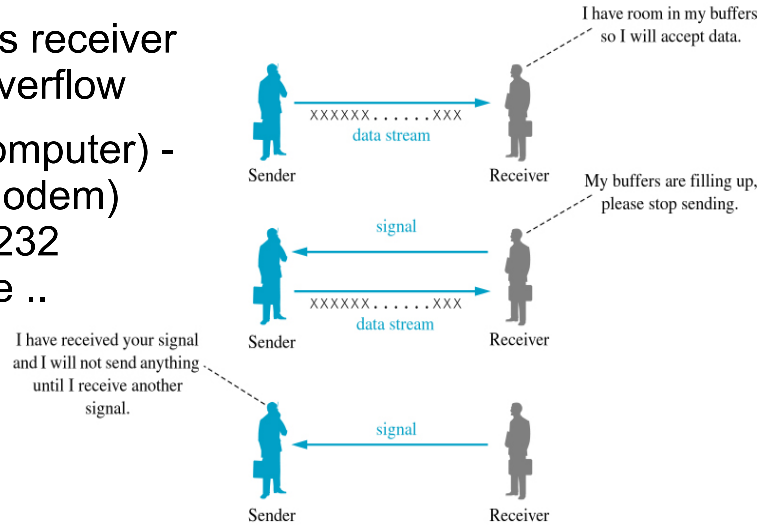
- Flow Control manages the flow of data so that the sender doesn't send too fast for the receiver
  - how can we send long messages, e.g. big files?
  - what happens when messages get lost, or are corrupted when they arrive?
  - what if the receiving *host* is busy, i.e. slow to accept incoming data?
  - how will a sender cope with lost (undelivered) messages?
  - will both hosts be able to send/receive at the same time?

What *is* Flow Control?

- Messages are broken into *frames* (or packets)
- Flow Control defines
  - “the way frames are sent, tracked and controlled”
  - may be simple or complex
  - Flow Control is a very basic kind of protocol

Signalling (Shay 8.2)

- *Receiver tells sender when it's ready to receive*
- Prevents receiver buffer overflow
- DTE (computer) - DCE (modem) via RS-232 interface ..



X-ON/X-OFF

- Over the DTE-DCE path ..
  - send ASCII X-OFF (0x13, ^S) to stop transmission
  - send X-ON (0x11, ^Q) to start it again
- This is *in-band* signalling, i.e. send signal on same path as data

- How quickly does the transmitter stop sending?
- How can we send 0x11 or 0x13 to the receiver?

Frame-oriented Control (Shay 8.3)

- Idea is to break large sequences of characters into smaller *frames*
- Frames are sent from one *user* (higher protocol layer) to another

- Simplest approach: “Unrestricted” protocol
  - just assume it's always safe to send
  - not really a useable protocol!

Stop-and-Wait

- Sender:
  - send frame, wait for ACK or NAK
  - if NAK, send frame again. Repeat until get ACK
- Receiver:
  - receive frame, check for errors
  - if OK, send ACK; otherwise send NAK

- No way to handle lost frames (therefore no ACK and no NAK)

"ACK" = acknowledge; "NAK" = negative ACK

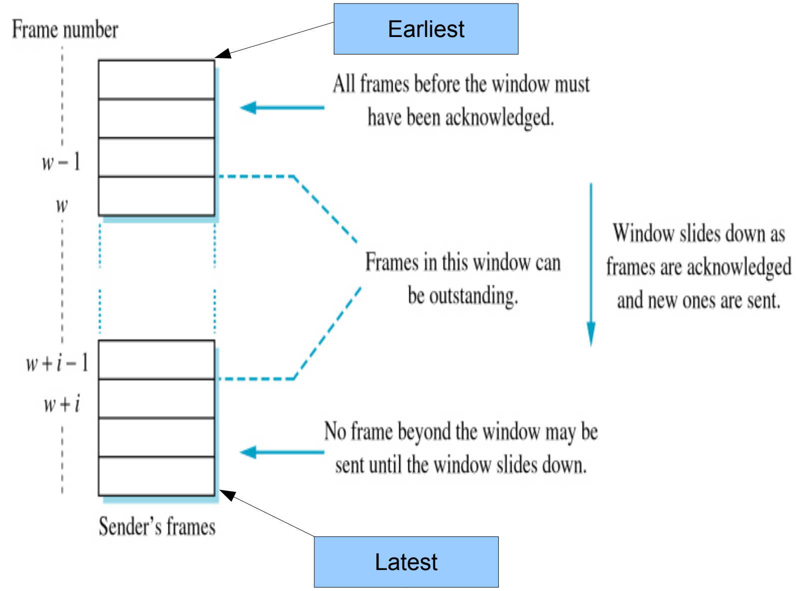
Protocol Efficiency: Effective data rate

- *Signal velocity* in wire or fibre is ~2/3 speed of light, i.e. 2×10^8 m/s
- Assume frame size is 1500 Bytes = 1500 x 8 bits = 12000 bits
- Assume transmission rate is 10 Mb/s = 10^7 b/s
- Then a frame takes 12000 /10^7 s = 1.2 ms to output on the wire
- Assume ACK is a 64 Byte frame → 0.0512 ms to output
- Auckland-Hamilton is about 120 km, so a signal takes *distance / velocity* = $(120 \times 10^3)/(2 \times 10^8)$ s = 0.6 ms to get there or back.
- Therefore, to send frame and receive ACK takes roughly 1.2 + 0.6 + 0.05 + 0.6 = 2.45 ms
- Effective bit rate is $12000/(2.45 \times 10^{-3})$ = 4.9 Mb/s
  - *49% efficient: half the time is wasted waiting for ACKs.*

Side note: a catch in the notation

- Convention:
  - Mb/s for megabits per second
  - MB/s for megabytes per second
- Often leads to confusion, especially with marketing people, journalists, and politicians.
- If there is any chance of confusion, write "megabits" or "megabytes" in full.
- In data communications, we normally discuss megabits. But when considering application throughput, megabytes are more useful.

Sliding Window (Shay 8.4)



Sliding Window

- Idea here is to have a maximum of *i* frames on the wire at any time. *i* is the *window size*
- Each frame has a sequence number, sender must remember each frame until it is ACKed
- Sender keeps track of *w*, sequence number of first (of *i frames*) in window. When frame *w* is ACKed, sender can forget it
- Window does not move until earliest frame has been ACKed. Then it can slide down one place.

Go-back-n

- Shay develops a frame format for two-way communication

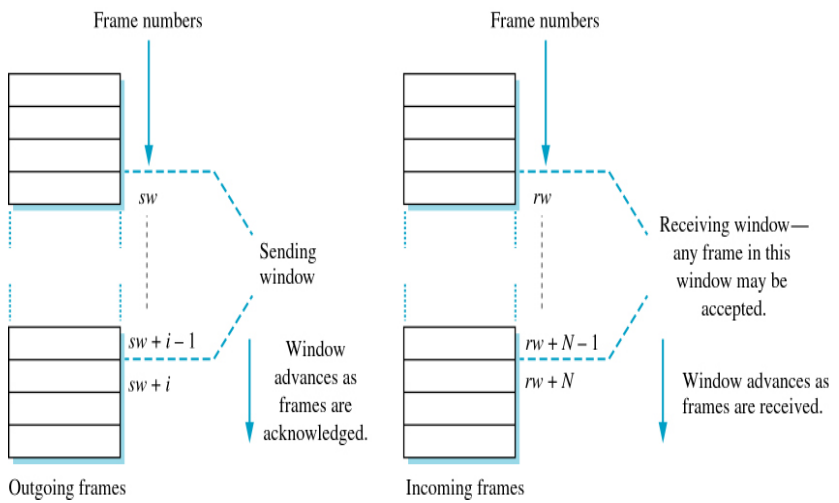
Source	Destination	Number	ACK	Type	...Data...	CRC

- Data frame in one direction can carry an ACK for the other direction, i.e. a *piggy-backed ACK*
- To handle lost frames, he has an *ACK timer* at the receiver and a *frame timer* at the transmitter
- When the receiver detects a missing ACK, it tells the transmitter to go back N packets and try again

Sequence Numbers

- Sequence Numbers fit in a K-bit field; there can be at most 2^K frames in the window
- K should be big enough to handle the maximum window size we expect to use
- They are *unsigned* numbers, and can *wrap,* i.e. count through 2^K-2, 2^K-1, 0, 1, 2, ... You can think of the sequence numbers as being arranged in a circle
- What happens if a host crashes and restarts?
- Some protocols used *lollipop sequence numbering* to handle restarts! (search Wikipedia)

Selective Repeat (Shay 8.5)



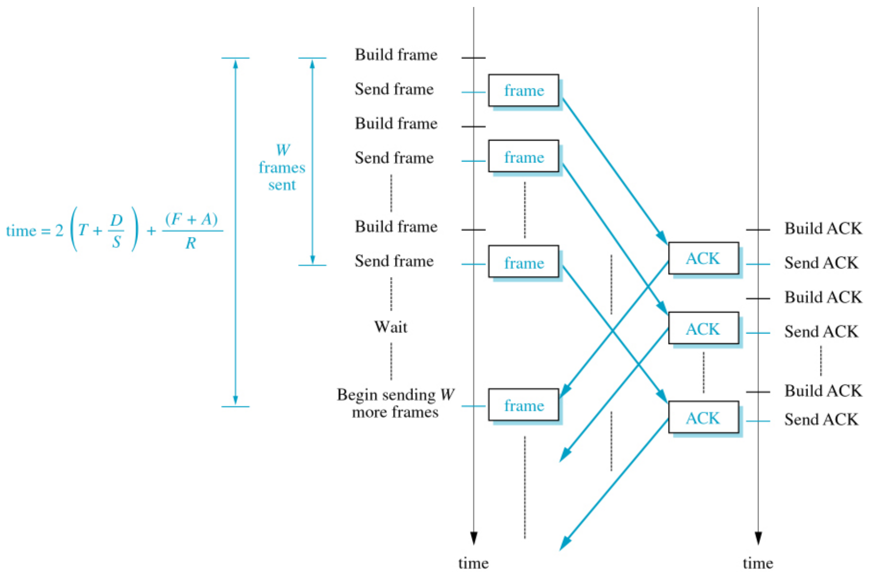
Selective Repeat (2)

- Any frame can be ACKed, specifying its sequence number
- Frames arriving out of sequence are *buffered* until earlier frames have been ACKed
- When a NAK is received, only the NAKed frame is resent (Go-Back-n resent the whole window!)
- If a frame timer expires (no ACK or NAK), only the timed-out frame is resent
- Piggy-backed ACK acknowledges the *last frame delivered to the user,* so the sender knows that all frames up to that one have been safely received

Efficiency of Sliding Window Protocols (8.6)

- For a particular window size, message size, transmission speed and link distance, we can "just work it out," as we did for stop-and-wait
  - Note that Shay gives formulae if you prefer that
- *We assume no lost or damaged packets !*
- Two cases
  - we get our first message ACKed before we've sent a whole window. That allows us to keep sending at full link speed
  - we have to wait for an ACK after sending a window, then we can send another window. Shay has a diagram illustrating this...

Sending whole window and waiting



Numerical example (1)

- Sending many 1500B frames in 20-frame windows, Auckland-Hamilton on a 10 Mb/s link
  - Just like Stop-and-Wait: 1.2 ms to output frame, 0.6+0.6=1.2 ms round-trip time.
  - Any window >2 frames can run at full speed, 10 Mb/s, because ACK will be back after 1.2 + 1.2 = 2.4 ms*, just in time to release the 3rd packet in the queue.
  - *99% efficient* (you'd be brave to claim 100%)

*We have ignored the 0.05 ms to output the ACK frame, because it is small compared to the other numbers.

Numerical example (2)

- Same thing, but with 64B data frames and a window size of 20 frames
  - send time is $(64 \times 8)/(10 \times 10^6)$ = 0.0512 ms
  - time to send 20 frames = 20 x 0.0512 = 1.024 ms
  - first ACK returns after 0.0512+1.2+0.0512 = 1.3024 ms*
  - effective bit rate is (20 * 64 * 8)/1.3024 = 7.862 Mb/s
  - → *79% efficient*
  - note the effect of using a *small frame size!* We would need a larger window to get near to 100% efficiency.

*In this case we could not ignore the 0.05 ms to output the ACK frame, since it is the same as a data frame.

Bandwith-Delay Product (BDP)

- BDP for a link = data rate x link delay*
- Auckland-Hamilton at 10 Mb/s:
  BDP = 10 Mb/s x 0.6 ms **= 6000 bits**
  = 750 B
- This is the maximum number of bits we can have 'on the wire'
- Need to have buffers **at least double this** so that transport protocol can keep the link busy
  - **fill the wire once, and then again before first ACK returns**
- Bigger frames sizes help to keep the link busy – less *protocol overhead*

**one-way delay, not round-trip time*

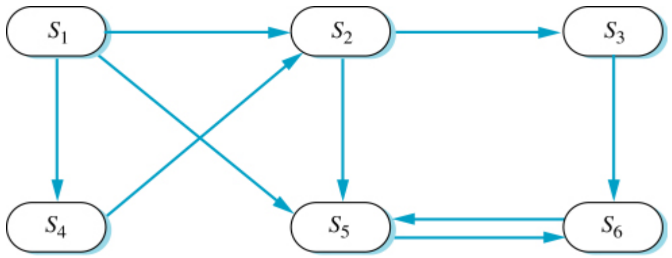
Take a deep breath... flow control methods

- X-ON/X-OFF
  - tell the other end to shut up
- Stop and wait
  - send one frame and wait for acknowledgment
- Sliding window
  - send multiple frames, and keep in step with acks
- Sliding window with go-back-N
  - simple error handling
- Sliding window with selective repeat
  - smarter error handling
- Later, we'll discuss TCP, the Internet's main flow control protocol.

Protocol Correctness (Shay 8.7)

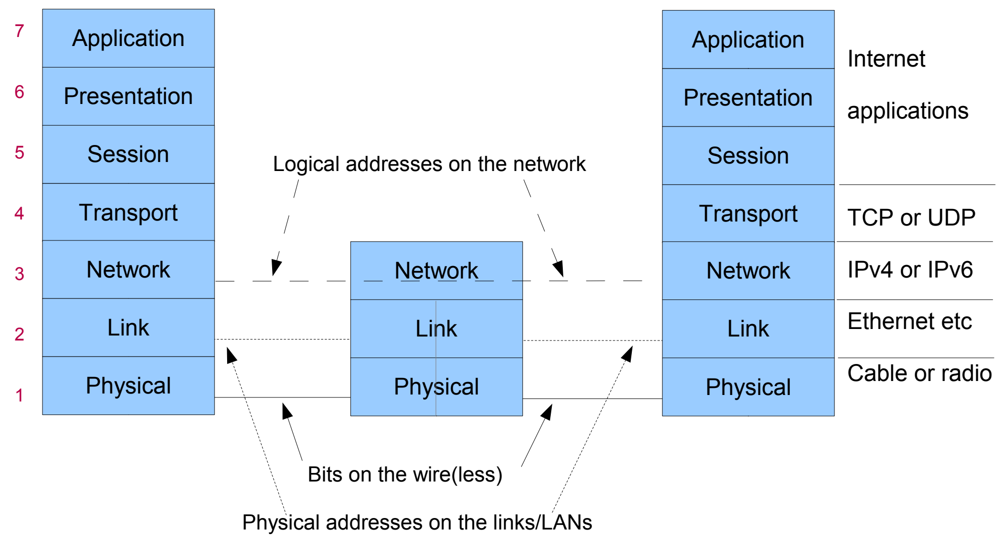
- Shay discusses two ways to describe systems:
  - Finite State Machines
  - Petri nets
- Finite State Machine models a system as being in one of a finite set of *states*
- State Transition Diagrams (STDs) are graphs, each vertex represents a state, and each edge a transition between states
- Petri nets are more detailed, we won't discuss them further

State Transition Diagrams



- Look for problems on graph
  - No edges pointing to S_1
  - $S_5 - S_6$ is an infinite loop
- This kind of analysis helps find flaws
  - *it doesn't prove correctness!*

Reminder: the formal model



Protocol Layers

- Layers are an abstraction. They provide a simple view of what happens in a communication system.
- Layer *n*
  - provides services to layer *n+1*
  - uses services from layer *n-1*
- The lectures about coding mainly concerned layers 1 and 2.
- Flow control can be used at various layers, e.g. 2 or 4.
- For the next few lectures we will talk about Local Area Networks (LANs), which provide layers 1 and 2.

Introduction to LANs (Shay 9.1)

- LANs connect many hosts (devices) together
- Link may be copper (coax or UTP), fibre or wireless
- Topology may be
  - *bus:* hosts share the link by taking turns
  - *ring:* access is controlled by passing a token round
  - *star:* each host is wired back to a hub
- Ethernet
  - today's most common LAN
  - started with a bus topology
  - morphed into a star over the years.

LAN Layers

- Layer 1 is the Physical layer.
  - On this layer, we've already looked at signaling and modulation methods.
- Layer 2, the Link layer, is where hosts talk to each other. Protocols here send frames (packets) to other hosts, and receive frames in response.
- Layer 3, the Network layer, is used to pass packets between LANs.
  - For example, we often use IP to pass packets between Ethernet hosts. We will see this later.

The story of the link layer (Shay 9.2)

- To properly understand modern link layer methods such as switched Gigabit Ethernet and WiFi, we need to understand the history of the link layer.
- To allow hardware products from different companies to work together, link layers have been standardised for many years.
  - International standards (mainly from the ITU)
  - US standards that have become dominant in the market (mainly from the IEEE 802 committee)
- We'll talk about HDLC, 802.2, Aloha, CSMA, Ethernet (802.3) and Wi-Fi (802.11)

High-Level Data Link Control (HDLC)

- Mainly intended for point-to-point links
- Designed before Local Area Networks existed in their modern form
  - a fore-runner of the IEEE 802.2 standard
- Still used when a simple serial connection is needed
- Frame-oriented link layer protocol
  - That is, a bit stream protocol with a frame structure

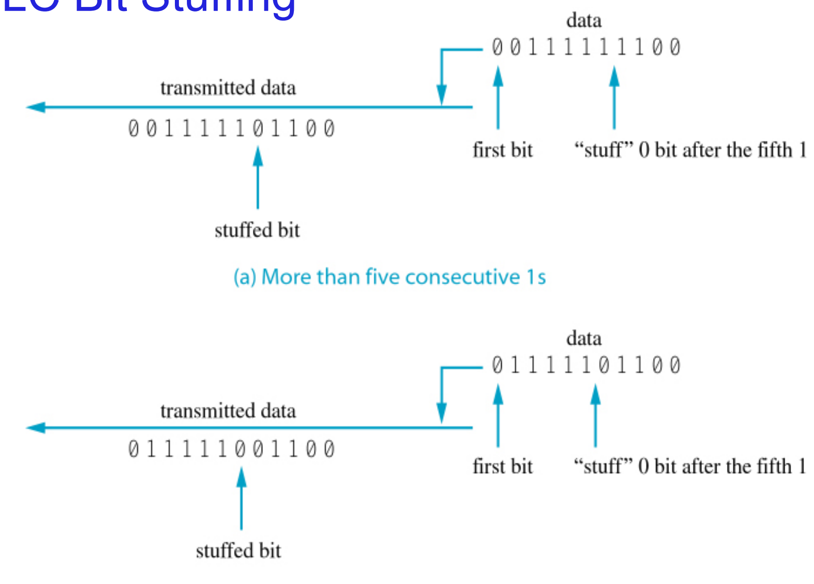
HDLC Frame Format

- *Flag* pattern, 01111110 (six 1s) marks start and end of frame. Receiver watches medium for flags

number of bits:	8	8 or 16	8 or 16	variable	16 or 32	8
	Flag	Address	Control	------- Data -------	FCS	Flag

- How do we send the flag pattern within the data part of the frame?

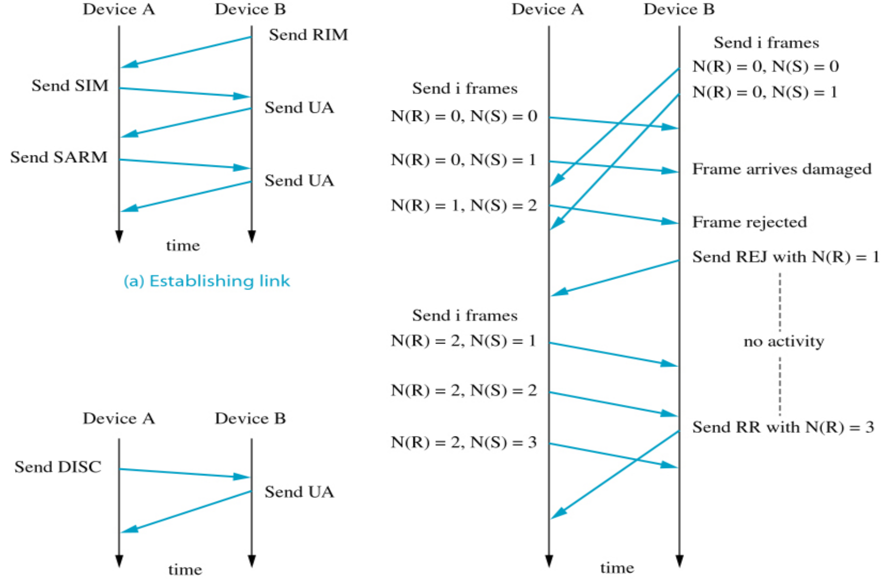
HDLC Bit Stuffing



(a) More than five consecutive 1s

(b) Five consecutive 1s

HDLC communication example



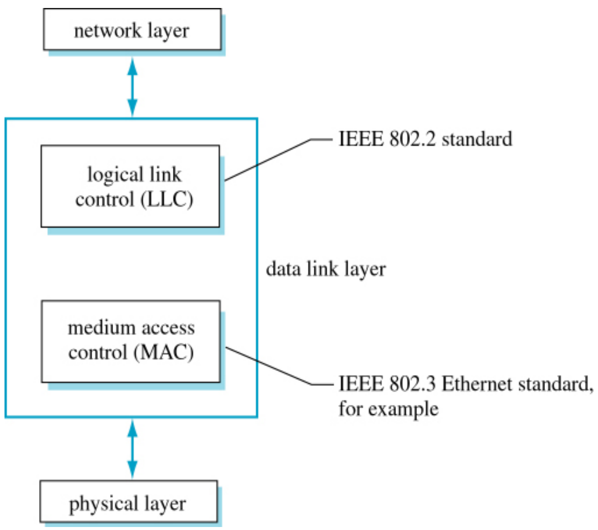
(a) Establishing link

(c) Terminating link

(b) Exchanging frames

IEEE 802 Data Link Control (Shay 9.2)

- Link layer is divided in two: LLC and MAC sublayers.



802.2 Logical Link Control (LLC)

- Mainly intended for Local Area Networks (but designed in the abstract)
- Frame-oriented link layer protocol
- As we'll see, a bit complicated

802.2 LLC Header Formats (if used)

General form of LLC header

DSAP address 8 bits	SSAP address 8 bits	Control field 8 or 16 bits	Information field... N*8 bits

- DSAP, SSAP are Service Access Point addresses
  - 04_{16} = IBM SNA
  - 06_{16} = IP
  - AA_{16} = SNAP (Subnetwork Attachment Point)
  - etc. (many values defined)

802.2 LLC Header Formats (if used)

DSAP address 8 bits	SSAP address 8 bits	Control field 8 or 16 bits	Information field N*8 bits

SNAP header (8 bytes)

AA AA 03 LLC	00 00 00 3 octet OUI	08 00 2 octet Ethertype	payload data

- OUI = Organisation Unique Identifier (zero for Ethernet types)
- Type field values are Ethernet type (Ethertype) values
  - 0800_{16} = IP, 0806_{16} = ARP, 6003_{16} = DECnet phase IV, ...

Isn't that a bit complicated?

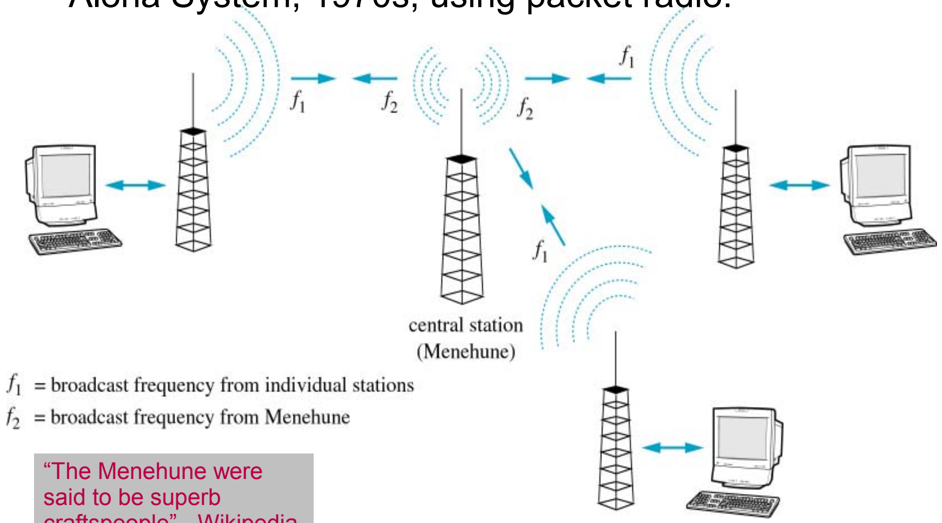
- Yes. LLC is quite complicated because it was designed by a committee, and it offers a lot of flexibility, enough to satisfy every member of the committee.
  - Flexibility in a protocol design usually makes it more complicated.
  - Did you notice two different ways to encapsulate IP?
  - Simple designs are usually more reliable, because there's less to go wrong.
  - Therefore, flexibility is not always a good thing.
- Personal opinion: LLC is a bad design.

Medium Access Control (MAC)

- We saw that this is part of Layer 2
- Why is it different from Flow Control?
  - Flow Control manages the flow of frames (or packets) so that the sender doesn't send too fast for the receiver
  - MAC manages physical access to the medium (cable, fibre, or wireless link) so that two senders don't talk at once
- Why is it different from multiplexing?
  - Multiplexing shares Layer 1 channel between multiple pairs of senders and receivers
  - MAC allows each sender full access to the channel, one at a time.
- Now we will discuss several MAC methods

Contention Protocols (Shay 4.7)

- Basic idea: Hosts must *share* the medium
- Aloha System, 1970s, using packet radio:



"The Menehune were said to be superb craftspeople" - Wikipedia

Aloha Protocol

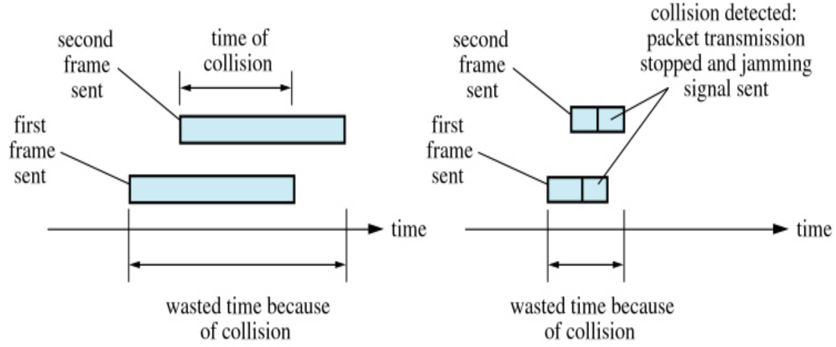
- Any host can broadcast a message to Menehune at any time
- If the message is received correctly, Menehune ACKs it (on a different frequency)
- If two host transmissions overlap (and interfere) the message is lost
- If a message is not ACKed the host assumes it was lost, waits a random time, then resends
- Worked and was simple, but not a very efficient use of the medium

Carrier Sense Multiple Access (CSMA)

- Like Aloha, *listen to medium* for any activity
- If no activity, transmit; otherwise wait
- Can still get collisions, various ways to reduce them:
  - use 'slot time,' hosts can only transmit at start of a slot
  - random choice, probability *p*, to decide whether to transmit or wait for next slot
  - Shay Fig. 4.44 compares various schemes

Collision Detection

- Start transmitting any time, but watch medium for a collision
- When collision detected, stop transmitting, send jam signal
- This is CSMA/CD



(a) Collision without detection (b) Collision detection

How to exit a stop sign using CSMA/CD