# Takeaway points – Protocols & Layers

- Protocols are the building block for networks. There are many different protocols. Protocols are standardized for interoperability.
- Protocols are combined using layering, a stylized form of use.
- Layer frameworks organize functionality into specific layers; the End-to-End argument is one guideline for placing functionality.
- IP is the single network protocol for the Internet, and it has enabled much innovation above and below.

# Takeaways – PHY layer

- Real wired, wireless, optical fiber links carry signals that represent bits. The signal modulates a carrier is for passband transmission. The signals are altered during transmission.

- There are fundamental limits (Shannon) on how much information links can carry. These depend on physical characteristics (bandwidth, signal attenuation).

- There are engineering considerations too, e.g., clock recovery, how to frame bits into messages.

- An abstract model of a link as rate, delay, error rate, and whether broadcast is usually all we need (except for wireless systems).

# Takeaways – Error Detection & Correction

- We add redundant data to detect/correct errors. Noise can cause errors in original or redundant data.
- Errors can be detected and data retransmitted (ARQ) or corrected using redundancy (FEC).
- Hamming distances tell us how sparsely the information is encoded in the received bits, hence how much error we can handle.
- We want to handle likely errors, so the pattern (random bits, bursts, other) and expression (flips, erasures) of errors affect what is a good codes
- Common detection schemes are CRCs and checksums (weaker). Common correction schemes are BCC, RS/BCH and LDPC codes (not covered). This is applied math.

# Takeaways – multi-access

- We can share channels in frequencies, time, and with codes. Sharing based on statistics is cost-effective.
- Randomized time schemes are well-suited to bursty data traffic and there are many variants (Aloha, CSMA, CSMA/CD, BEB for Ethernet). They are simple but have overhead for collisions.
- Wireless is complicated by the difficulty of spatial reuse (hidden/exposed terminals and RTS/CTS) and detecting collisions (CSMA/CA).
- Turn-taking designs (around a ring, a bus, a distributed queue) can avoid collisions. They are more complicated but better suited to deterministic service.

# Takeaways -- bridging

- We can connect PCs together with a LAN switch to make a LAN; we can connect LANs with LAN switches (bridges) to make a larger (extended) LAN.

- LAN switches (bridges) are plug-and-play. The emphasis is “something simple that works” not “good performance and lots of operator control”.

- LAN switches learn which ports to use to forward traffic and organize into a spanning tree using a distributed algorithm (that all nodes run asynchronously in parallel).

# Takeaways – shortest path routing

- Shortest path routing assigns costs to links and finds the shortest paths through the network graph.
- Routing is the process of building up a local model of the network, forwarding is the process of sending packets on their way using the model.
- In Distance Vector (DV) routing, nodes exchange best vectors with their neighbors and the system converges to the best routes. It is simple, but failures can lead to convergence problems.
- In Link State (LS) routing, nodes flood the topology, then each node uses the whole topology to compute routes. It is more complex, but has better transient properties. LS routing is widely used in most networks today.

# Takeaways -- Internets

- Internetwork is a network of different networks; Internet is key internetwork
- Issues of heterogeneity: different packet lengths and fragmentation / path MTU discovery; new level of addressing plus allocation (registries and DHCP) and translation (ARP)
- Issues of scale: hierarchical address blocks for networks; routing and forwarding based on IP prefixes (CIDR)

# Takeaways – Interdomain routing

- Routing across networks of networks rather than routing within one network
- Issues of scale: use hierarchy to treat ISP as single network and aggregation via IP prefixes.
- Issues of policy: choose routes based on commercial preferences, no longer shortest path; done with a path vector policy.