The Link Layer: Addressing, Error Detection, & Correction

CS 352, Lecture 19, Spring 2020

http://www.cs.rutgers.edu/~sn624/352

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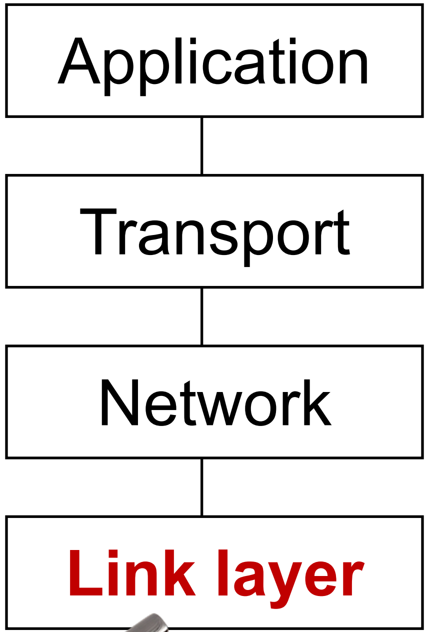
Course announcements

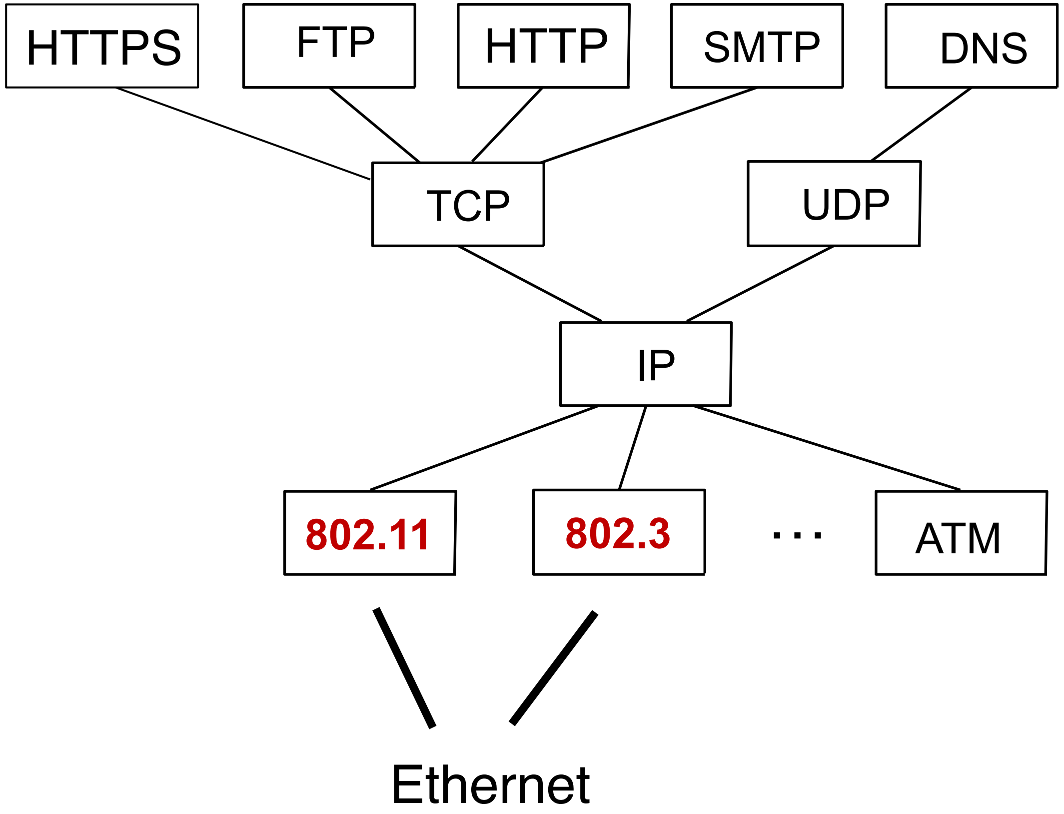
- Project 3 released
- Ensure you attend recitation this week
  - Avoid setup issues by walking together with the TA
  - Resolve any issues by asking TAs right there
  - Download (large) mininet VM and install VirtualBox before the recitation
- Quiz 7 due next Tuesday
- Final exam dates shifted slightly
  - The exam window is now May 7 @ 7 PM to May 12 @ 7 PM
  - Conditions and honor code same as mid-term 2
  - Covers all lectures
  - All multiple-choice questions

Network layer: the big picture

- The network layer provides connectivity between Internet hosts
  - Split into control plane and data plane
- Data plane: the IP protocol
  - Supported by DHCP, ICMP, NATs
  - Routers implement data plane through ports + fabric + queues
- Control plane: routing protocols
  - Link state: flooding + centralized information + independent computations across routers
  - Distance vector: neighbor exchange + decentralized + dependent computations across routers
  - Path vector: flooding + decentralized + policy-based dependent computations across routers
- Quality of service: isolation, work conservation
  - Shaping vs. policing; leaky buckets vs. token buckets

The Link layer

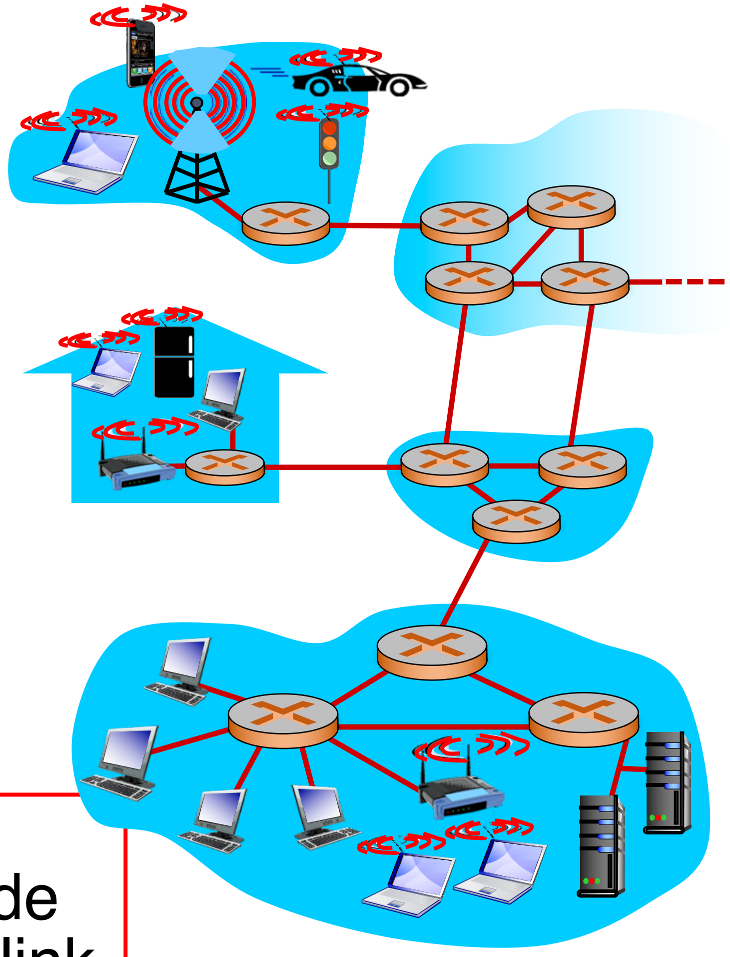




Link layer: introduction

terminology:

- hosts and routers: nodes
- communication channels that connect adjacent nodes along communication path: links
  - wired links
  - wireless links
  - LANs
- layer-2 packet: frame, encapsulates datagram



data-link layer has responsibility of transferring datagram from one node to *physically adjacent* node over a link

Link layer: context

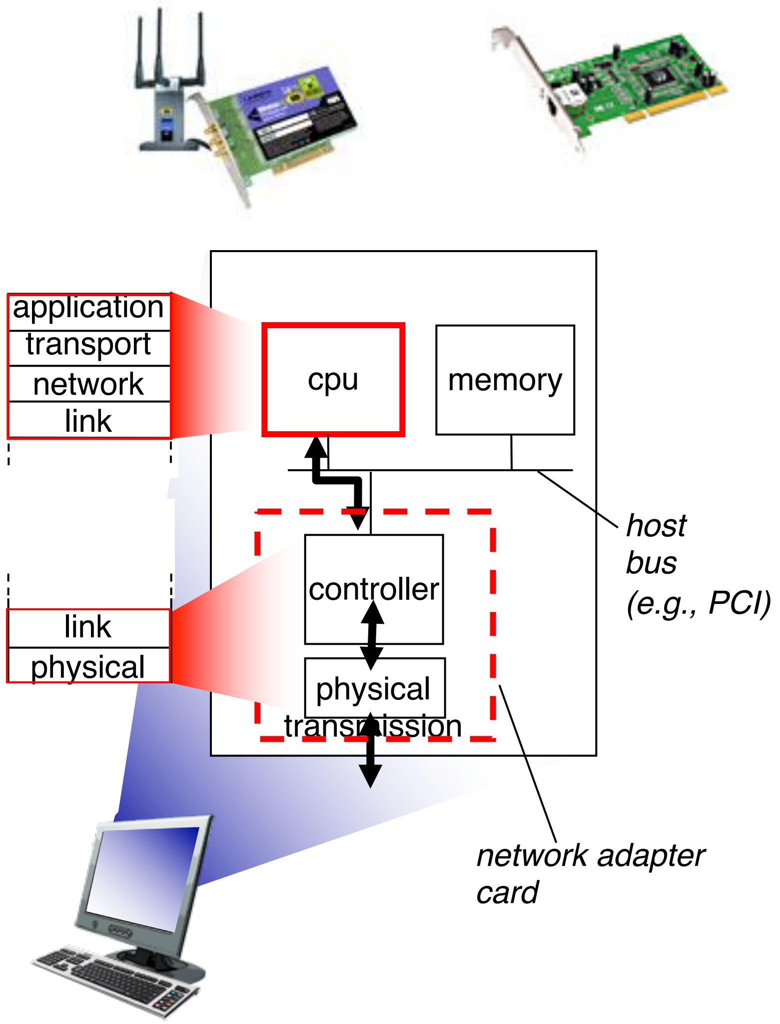
- datagram transferred by different link protocols over different links:
  - e.g., Ethernet on first link, frame relay on intermediate links, 802.11 on last link
- each link protocol provides different services
  - e.g., may or may not provide reliability over link

transportation analogy:

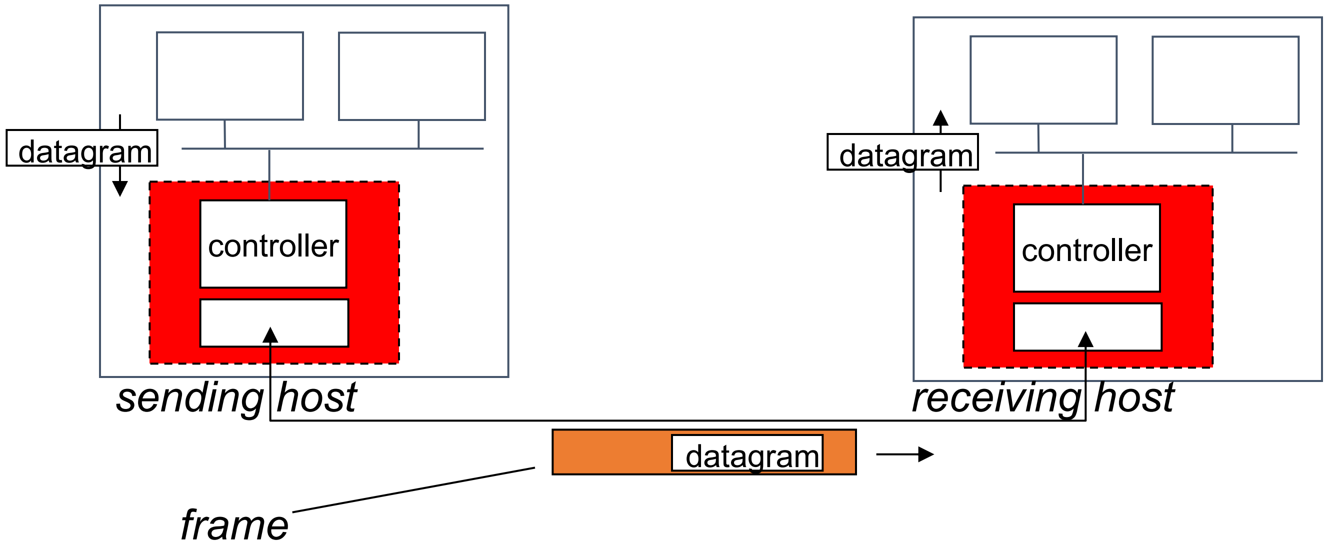
- trip from Piscataway to Lausanne
  - limo: Piscataway to JFK
  - plane: JFK to Geneva
  - train: Geneva to Lausanne
- tourist = datagram
- transport segment (road/flight/rail) = communication link
- transportation mode (car/plane/train) = link layer protocol
- travel agent = routing algorithm

Where is the link layer implemented?

- in every host
- link layer implemented in "adapter" (aka *network interface card* NIC) or on a chip
  - Ethernet card, 802.11 card; Ethernet chipset
  - implements link, physical layer
- Adapter attaches into host's system buses (PCI)
- Link layer: a combination of hardware, software, firmware



Adapters communicating



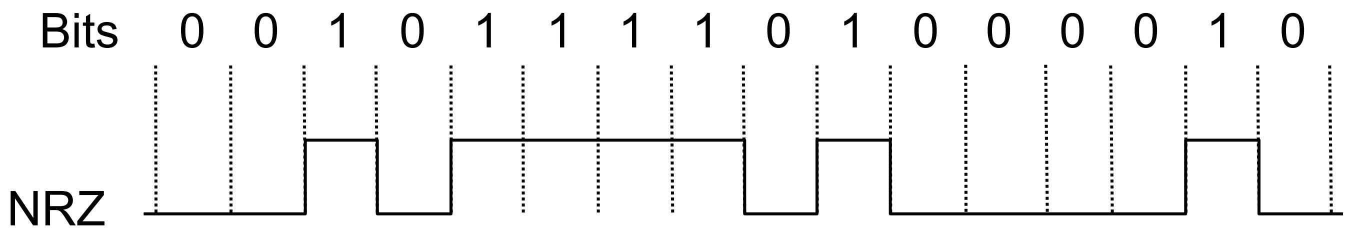
- sending side:
  - encapsulates datagram in frame
  - adds reliability/error checking bits
- receiving side
  - Check for errors
  - extracts datagram, passes to upper layer at receiving side (usually: link layer address must match)

Link layer services

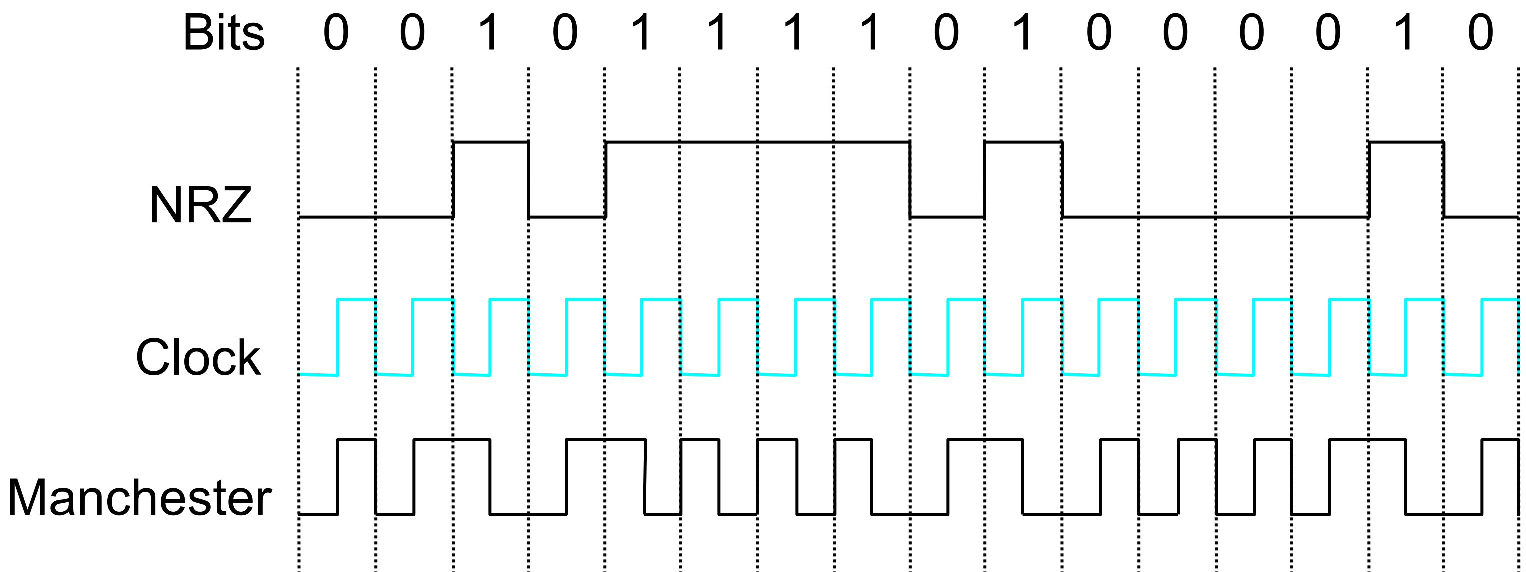
- *Encoding*
  - convert bits to signals and recover bits from received signals
- *framing, link access:*
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
  - "MAC" addresses used in frame headers to identify source, destination
    - different from IP address!
- *reliable delivery between adjacent nodes*
  - we learned how to do this already (chapter 3)!
  - seldom used on low bit-error link (fiber, some twisted pair)
  - wireless links: high error rates
    - *Q:* why both link-level and end-end reliability?

Encoding

- Signals propagate over a physical medium
  - modulate electromagnetic waves
  - e.g., vary voltage
- Encode binary data onto signals
  - e.g., 0 as low signal and 1 as high signal
  - known as Non-Return to zero (NRZ)
  - Problem: consecutive 1s and 0s, noise levels



Encodings (cont'd)

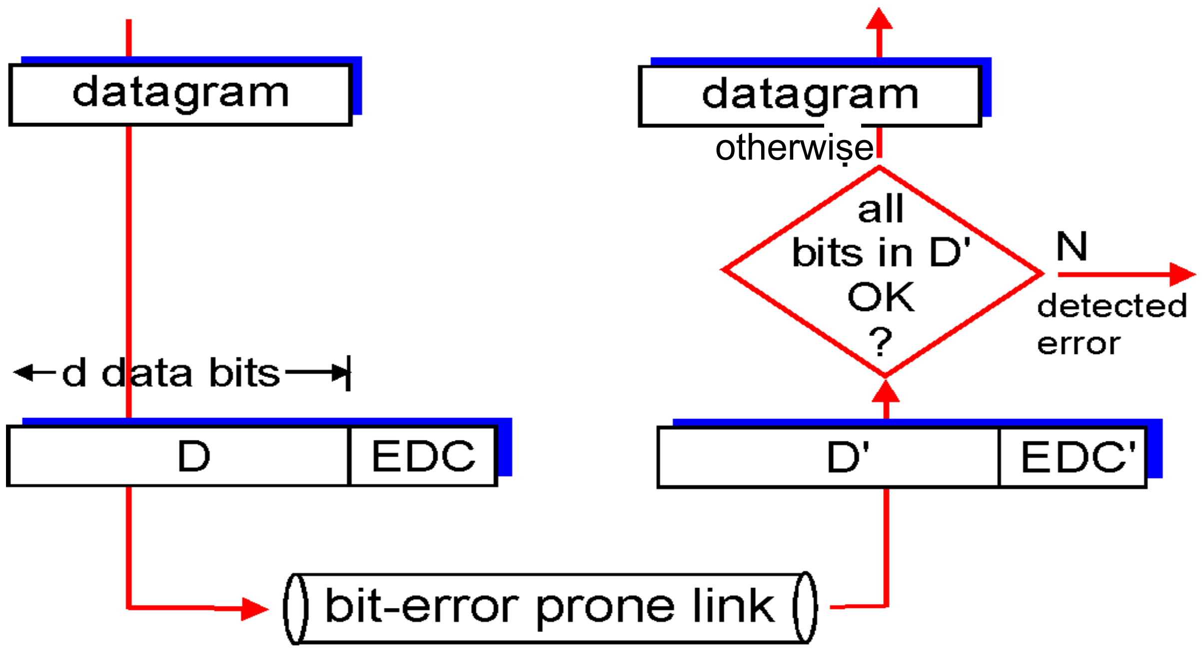


- Manchester encoding: +ve transition → 0; -ve transition → 1
- XOR(bit,clock)

Error detection

EDC = Error Detection and Correction bits (redundancy)
D = Data protected by error checking, may include header fields

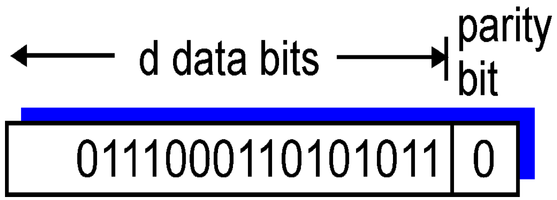
- Error detection not 100% reliable!
  - protocol may miss some errors, but rarely
  - larger EDC field yields better detection and correction



Parity checking

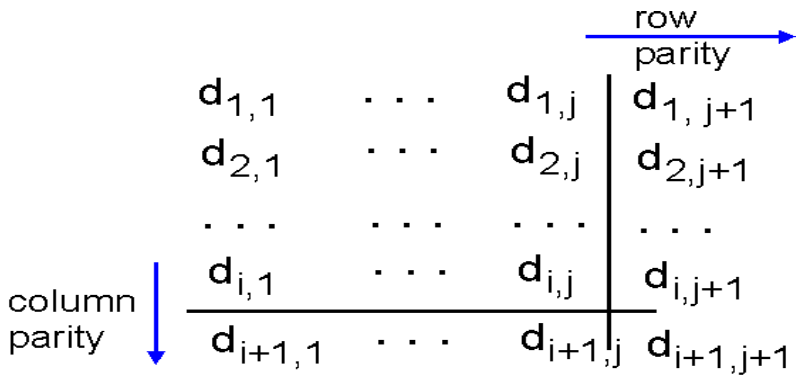
single bit parity:

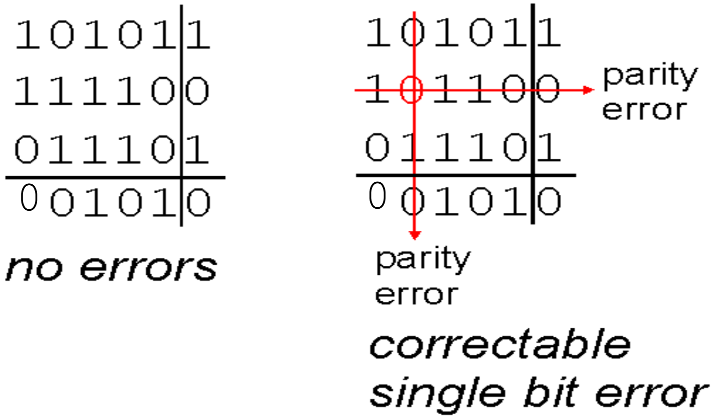
- detect single bit errors



two-dimensional bit parity:

- detect and correct single bit errors





Internet checksum (review)

goal: detect "errors" (e.g., flipped bits) in transmitted packet (note: used at transport layer only)

sender:

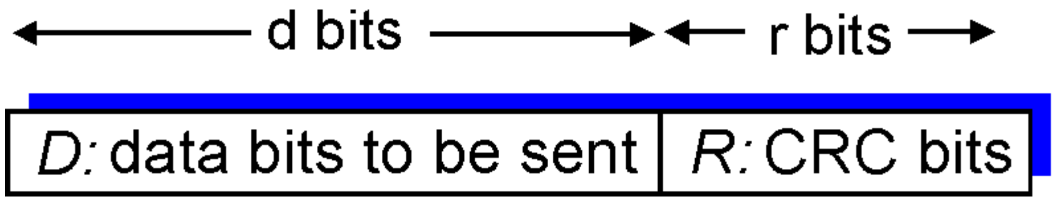
- treat segment contents as sequence of 16-bit integers
- checksum: addition (1's complement sum) of segment contents
- sender puts checksum value into UDP checksum field

receiver:

- compute checksum of received segment
- check if computed checksum equals checksum field value:
  - NO - error detected
  - YES - no error detected. *But maybe errors nonetheless?*

Cyclic redundancy check

- more powerful error-detection coding
- view data bits, D, as a binary number
- choose r+1 bit pattern (generator), G
- goal: choose r CRC bits, R, such that
  - <D,R> exactly divisible by G (modulo 2)
  - receiver knows G, divides <D,R> by G. If non-zero remainder: error detected!
  - can detect all burst errors less than r+1 bits
- widely used in practice (Ethernet, 802.11 WiFi, ATM)



bit pattern

$$D * 2^r \quad \text{XOR} \quad R$$

mathematical formula

CRC example

want:

$D \cdot 2^r$ XOR $R = nG$

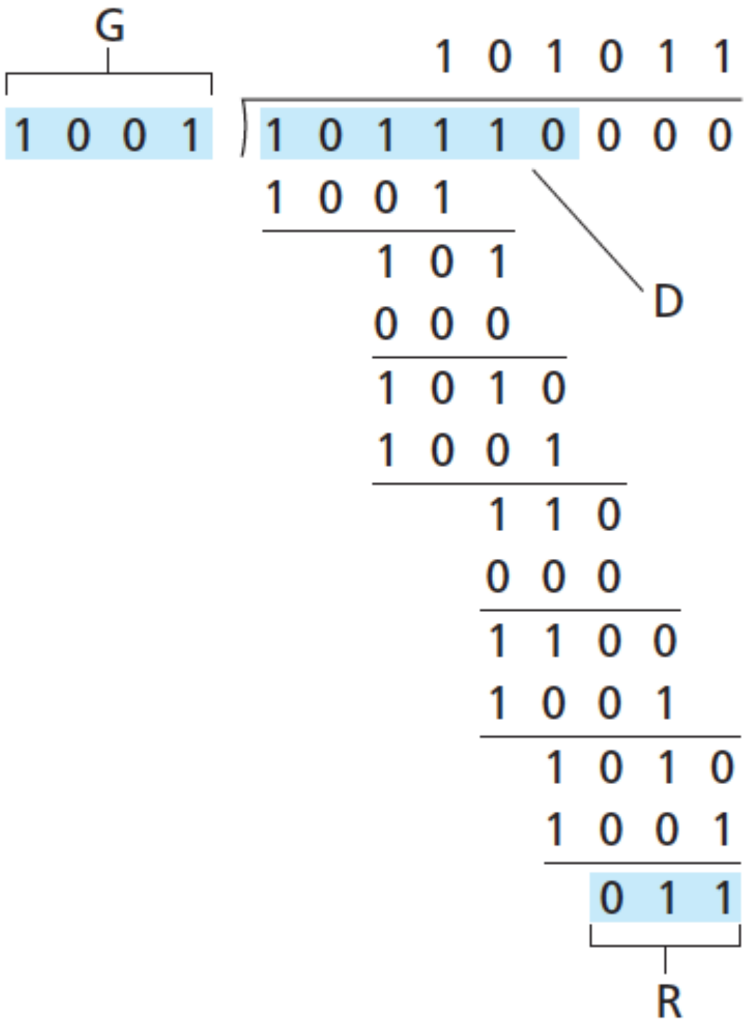
equivalently:

$D \cdot 2^r = nG$ XOR R

equivalently:

if we divide $D \cdot 2^r$ by G, want remainder R to satisfy:

$$\boxed{R = \textit{remainder}\left[\frac{D \cdot 2^r}{G}\right]}$$



ARP

How to get a MAC address for an IP address?

ARP: Address Resolution Protocol

- By default, NICs only pass on packets destined to their destination MAC address to the higher layers
- In a broadcast-based LAN, each source needs to know its destination's MAC address
- After a packet reaches a router, the link layer header needs to be added to reflect the destination host on that link
- ARP returns a link layer address when given an Internet address
- Communication requires IP → MAC address translation

ARP packet format

Internet Protocol (IPv4) over Ethernet ARP packet

Octet offset	0	1
0	Hardware type (HTYPE)	
2	Protocol type (PTYPE)	
4	Hardware address length (HLEN)	Protocol address length (PLEN)
6	Operation (OPER)	
8	Sender hardware address (SHA) (first 2 bytes)	
10	(next 2 bytes)	
12	(last 2 bytes)	
14	Sender protocol address (SPA) (first 2 bytes)	
16	(last 2 bytes)	
18	Target hardware address (THA) (first 2 bytes)	
20	(next 2 bytes)	
22	(last 2 bytes)	
24	Target protocol address (TPA) (first 2 bytes)	
26	(last 2 bytes)	

Hardware type: ex: Ethernet (1)
Hardware address length: 6 octets

Protocol Type: ex: IPv4 0x0800 (requesting IPv4 addr)
Protocol address length: 4 octets

Opcode ARP request:1

Opcode ARP reply:2

ARP operation