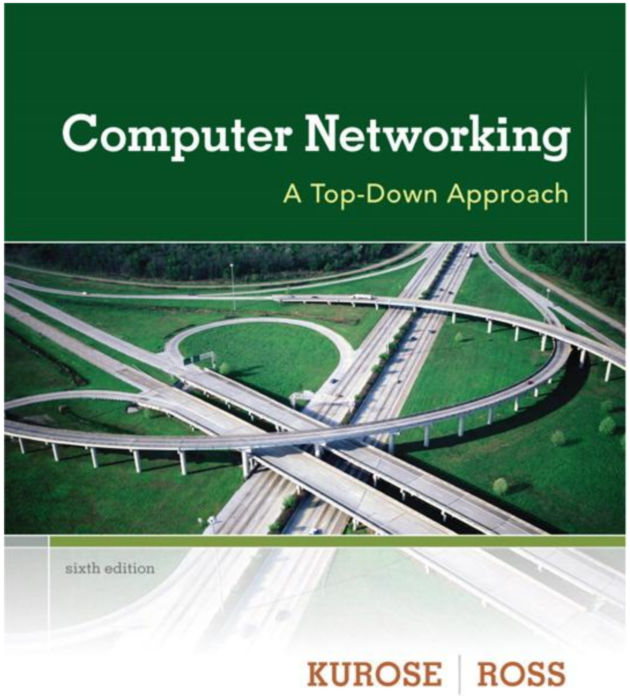
The Book

Start Reading Chapter 5 Now



Chapter 5: Link layer

our goals:

- understand principles behind link layer services:
  - error detection, correction
  - sharing a broadcast channel: multiple access to it
  - link layer addressing
  - local area networks: Ethernet, VLANs
- instantiation, implementation of various link layer technologies

Link layer, LANs: outline

5.1 introduction, services

5.2 error detection, correction

5.3 multiple access protocols

5.4 LANs
- addressing, ARP
- Ethernet
- switches
- VLANS

5.5 link virtualization: MPLS

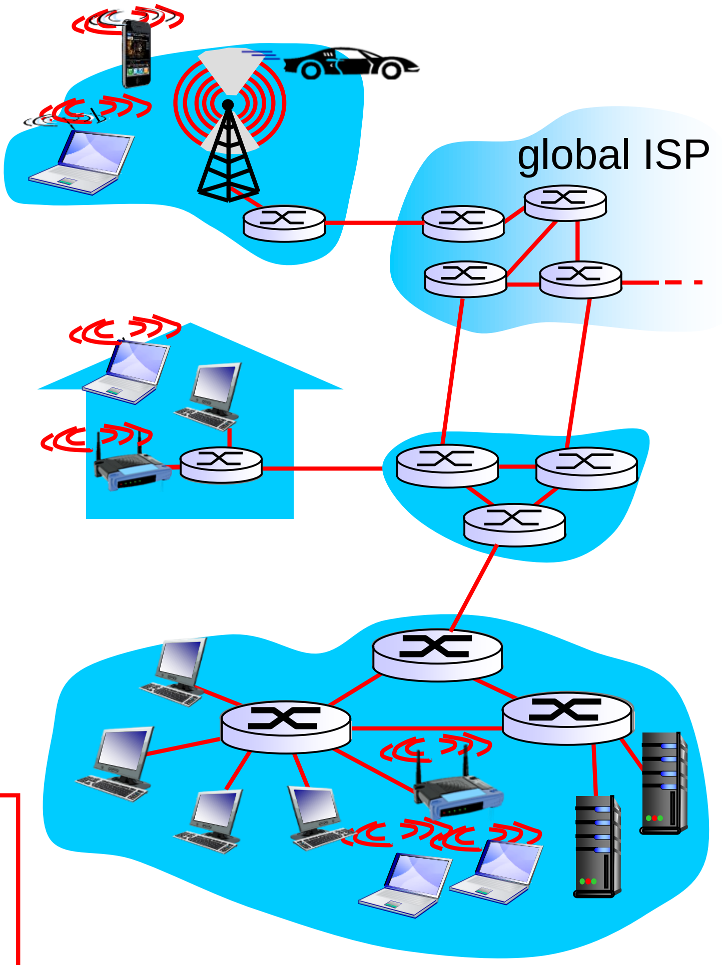
5.6 data center networking

5.7 a day in the life of a web request

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

- no more planning of routes at this layer!
- 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 reliable data transfer over link

transportation analogy:

- trip from *Corvallis* to *Washington State Convention Center (WSCC)*:
  - car: Corvallis to Seattle Westin.
  - walk: Seattle Westin to monorail station.
  - train: monorail station to WSCC.
- tourist = datagram
- transport segment = communication link
- transportation mode = link layer protocol
- travel agent = routing algorithm (at different layer)

Link layer services

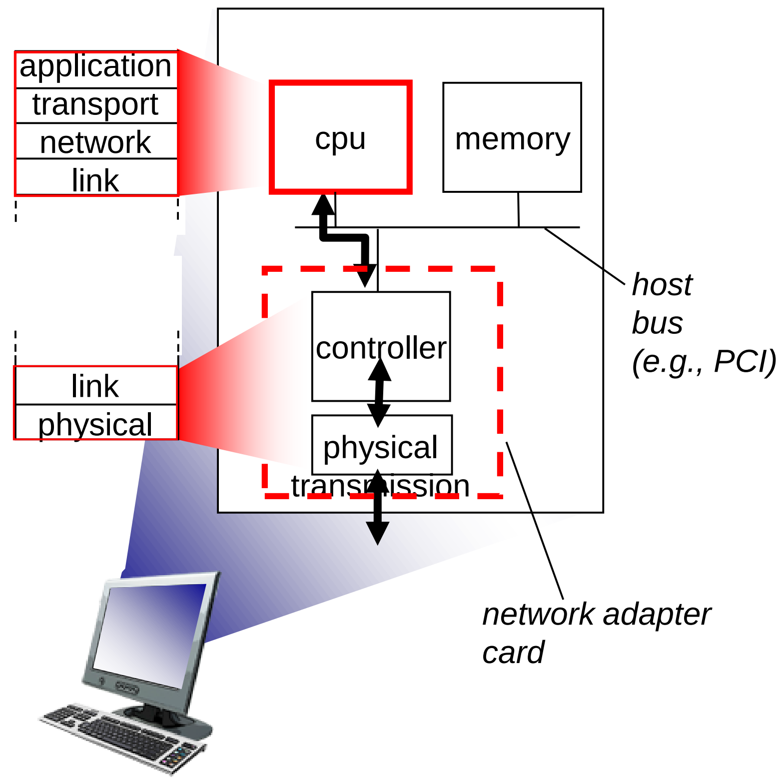
- *framing, link access:*
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
  - Media Access Control (MAC) addresses used in frame headers to identify source and destination
    - different from IP address!
- *reliable delivery between adjacent nodes*
  - 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?

Link layer services (more)

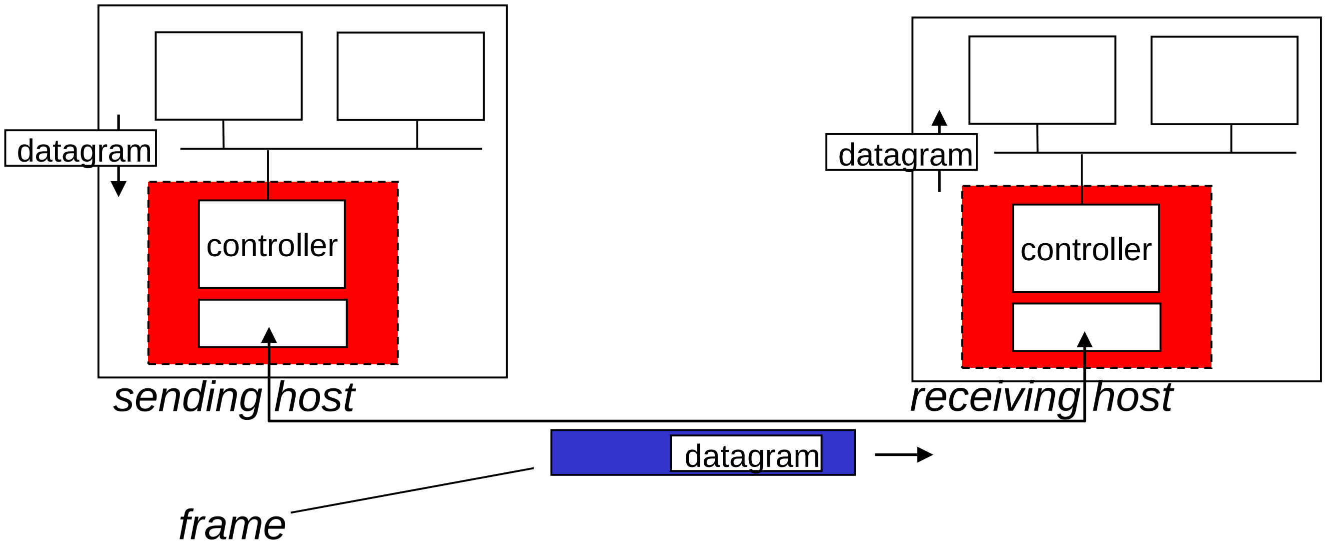
- *flow control:*
  - pacing between adjacent sending and receiving nodes
- *error detection:*
  - errors caused by signal attenuation, noise.
  - receiver detects presence of errors:
    - signals sender for retransmission or drops frame
- *error correction:*
  - receiver identifies *and corrects* bit error(s) without resorting to retransmission
- *half-duplex and full-duplex*
  - with half duplex, nodes at both ends of link can transmit, but not at same time
  - with full duplex, both can transmit at the same time

Where is the link layer implemented?

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



Adaptors communicating



- sending side:
  - encapsulates datagram in frame
  - adds error checking bits, manages, reliable data transfer (rdt), flow control, etc.
- receiving side
  - looks for errors, rdt, flow control, etc
  - extracts datagram, passes to upper layer at receiving side

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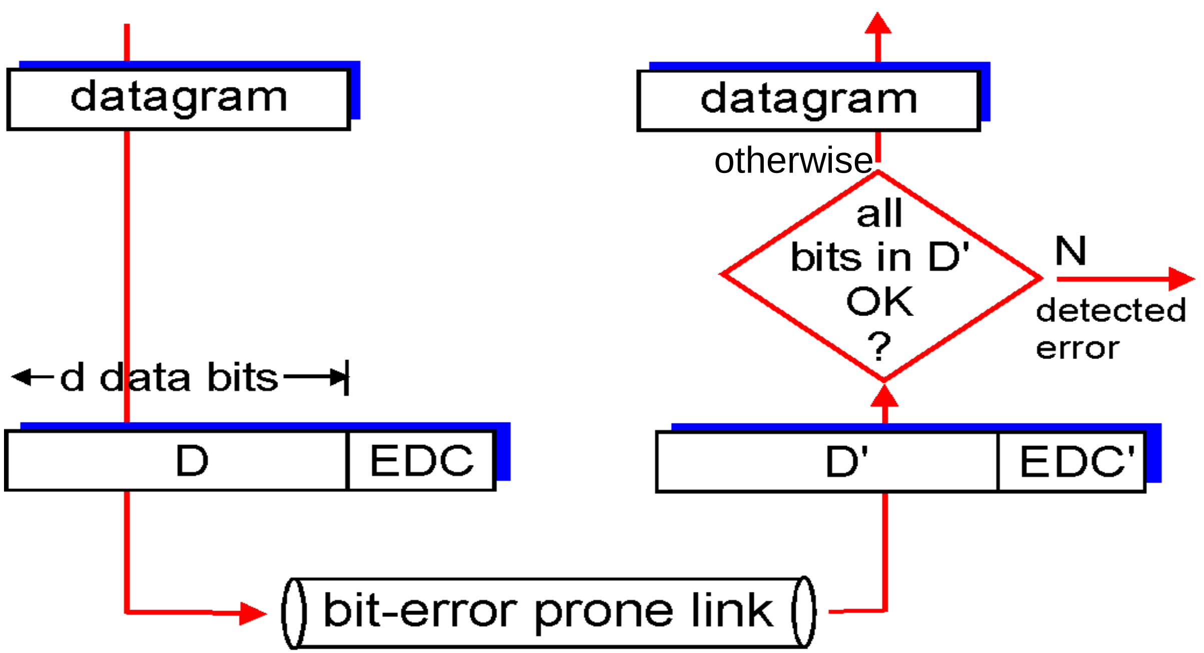
Error detection

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 theory

single bit parity:

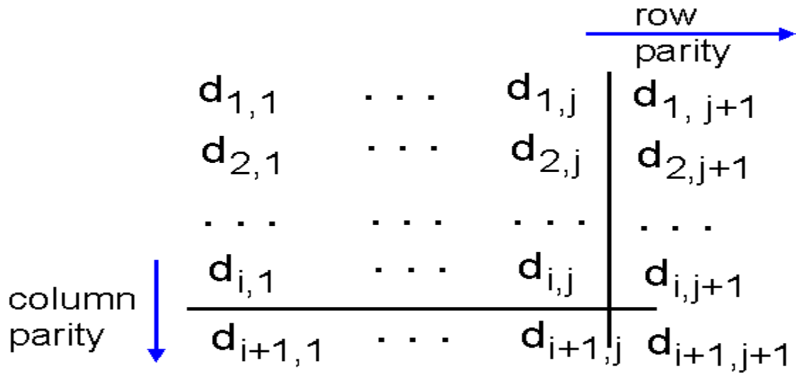
- detects single bit errors.
- The parity bit is 1 if the number of 1s is odd.
- The parity bit is 0 if the number of 1s is even.

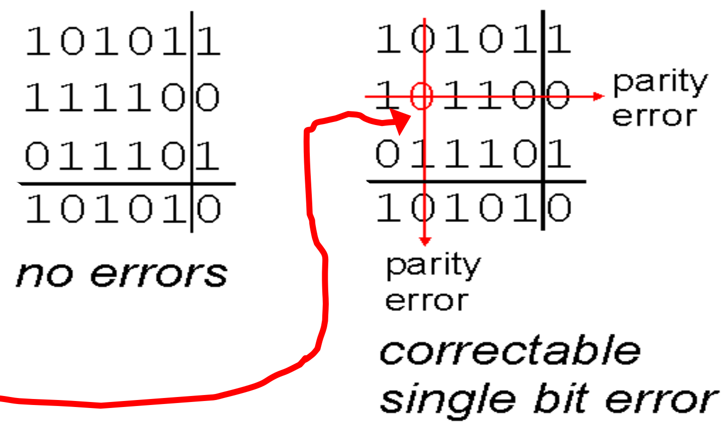
DATA	PARITY
10101	1
11110	0
01110	1

Change that 0 to a 1!

two-dimensional bit parity:

- detect and *correct* single bit errors
- requires grouping transmissions into blocks





Internet checksum (review)

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

sender:

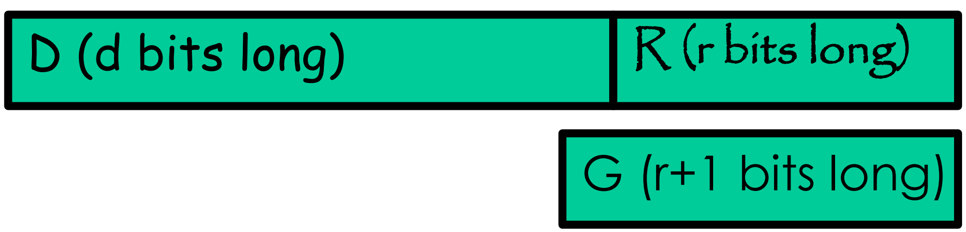
- treat segment contents as sequence of 16-bit integers
- checksum: addition (1's complement sum) of segment contents
- sender puts checksum value into UDP checksum field

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?*

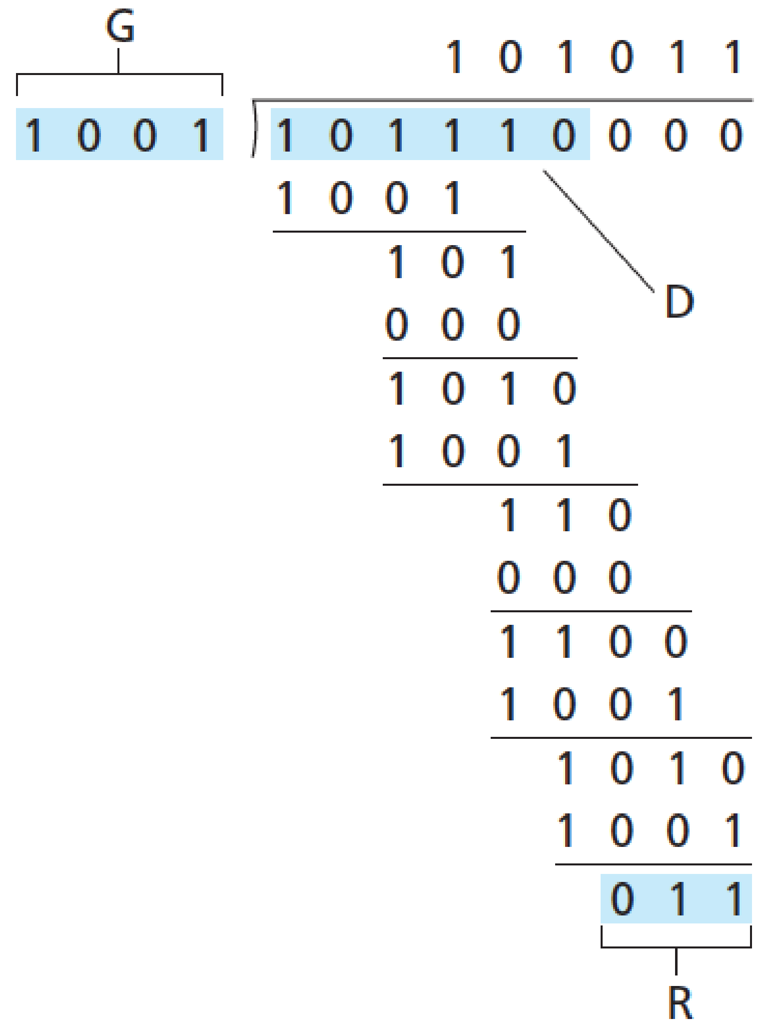
Cyclic redundancy check

- more powerful error-detection coding
- view d data bits as a binary number D
- choose bit pattern (called a "generator") of r+1 bits as binary number G
- sender: choose r CRC bits as a binary number R such that entire binary number DR exactly divisible (*using XOR*) by G
- receiver divides DR by G (*using XOR*): 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)



CRC example

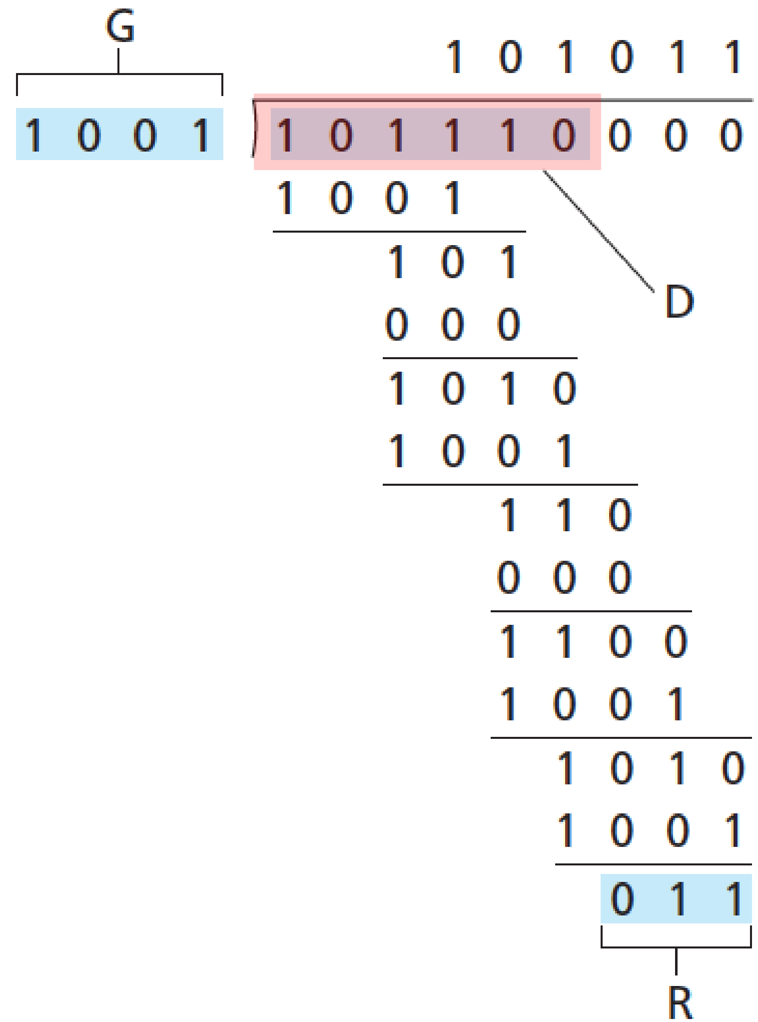
- Sender wants to calculate DR



CRC example

- **1)** Bit shift left (i.e. multiply by 2) by size of G – 1

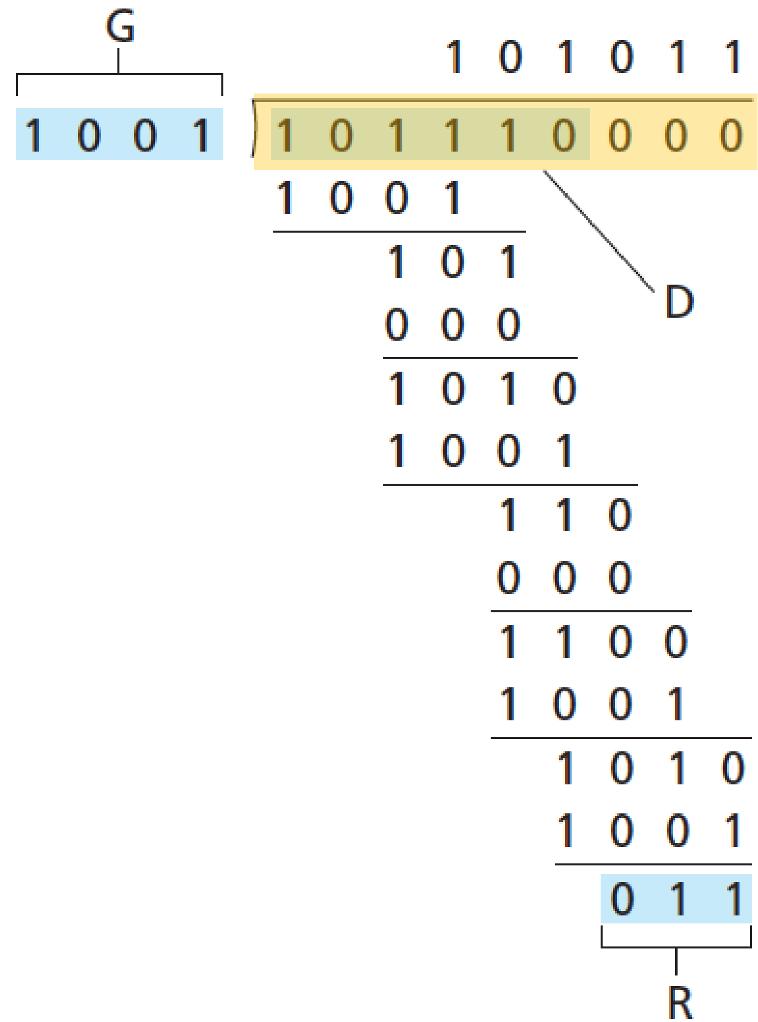
- 101110 turns into…



CRC example

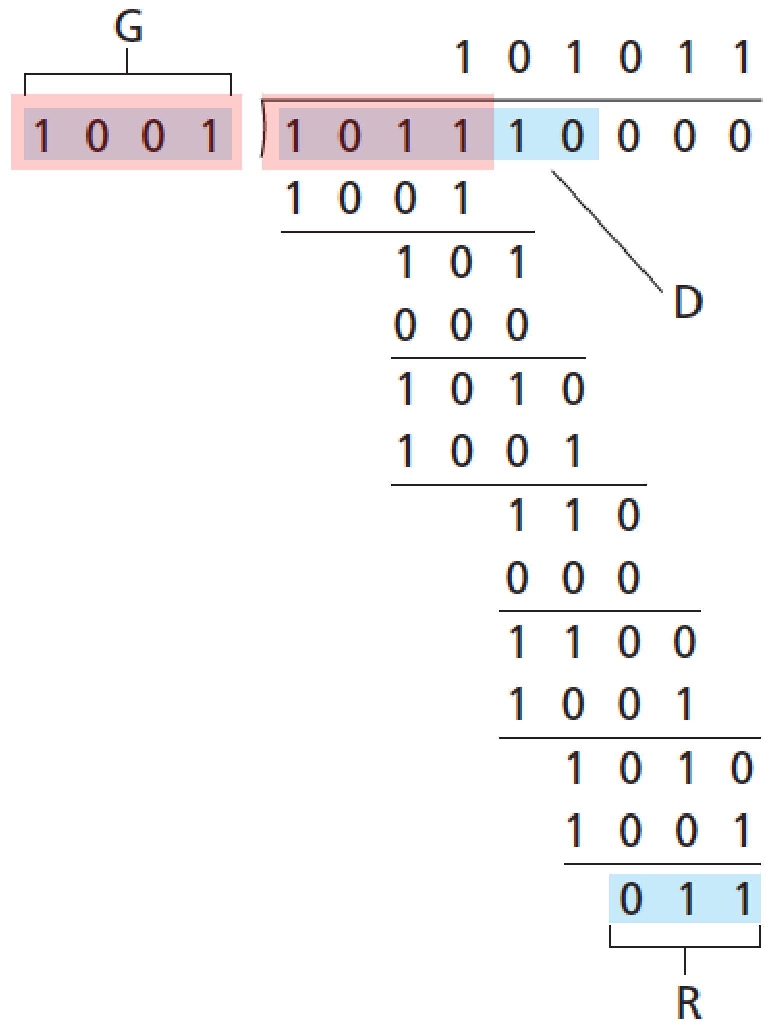
- **1)** Bit shift left (i.e. multiply by 2) by size of G – 1

- 101110
  turns into
  101110 000



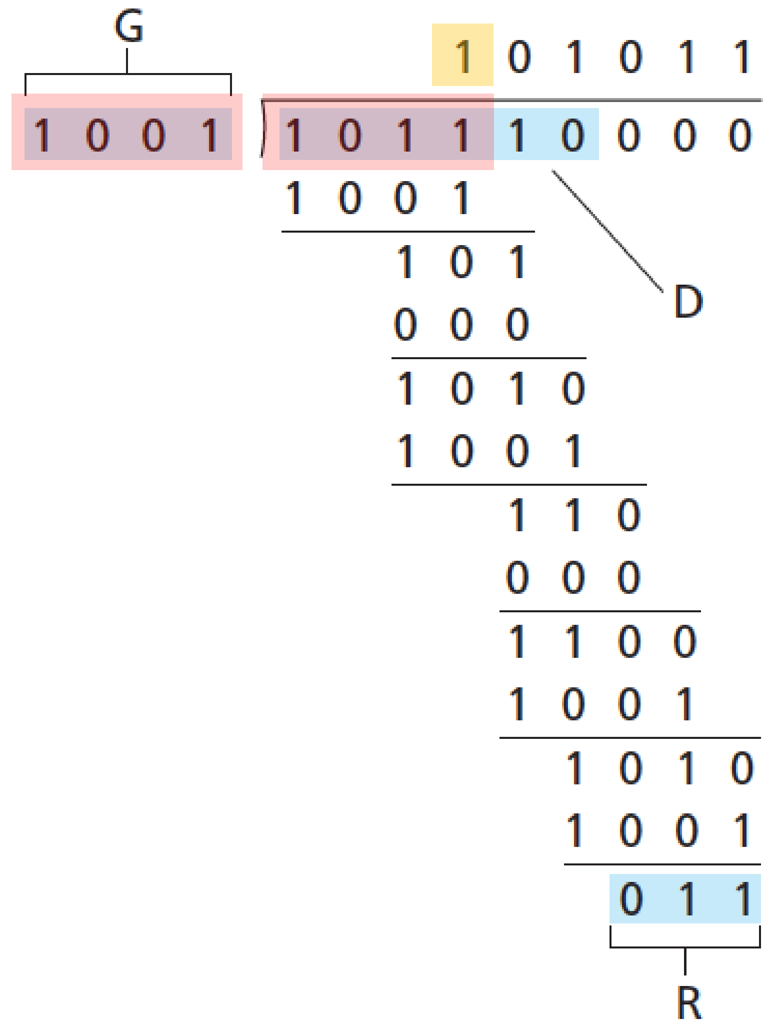
CRC example

- 2) Divide by G
- How many times does 1001 go into 1011?



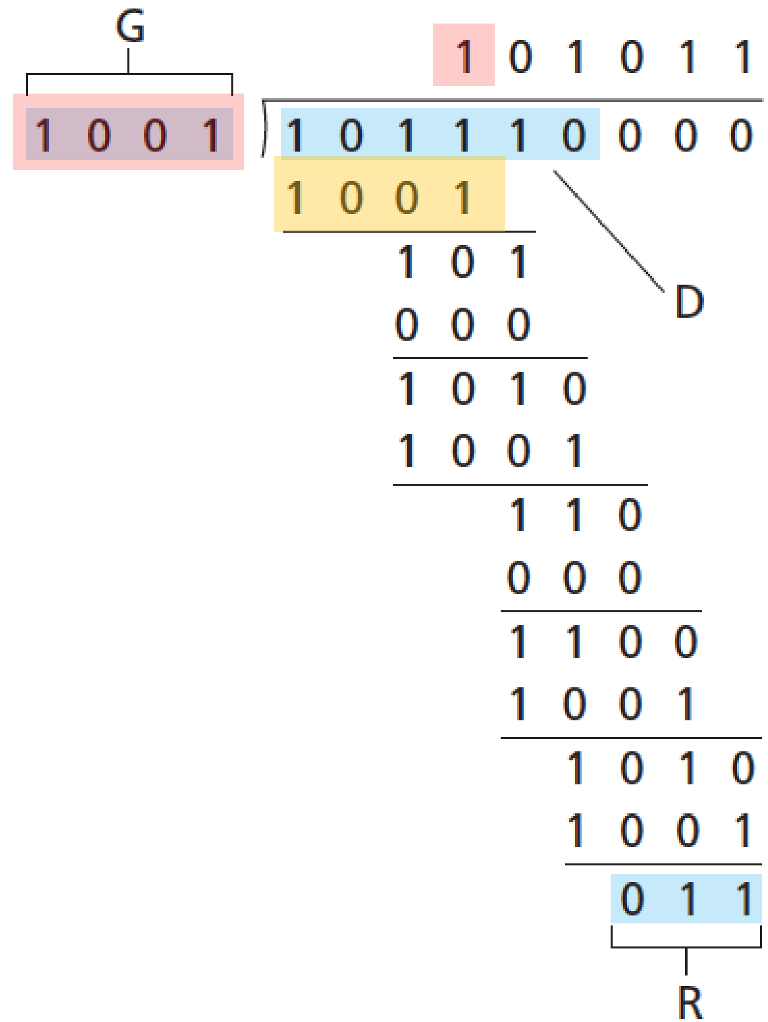
CRC example

- How many times does 1001 go into 1011?
- Once!



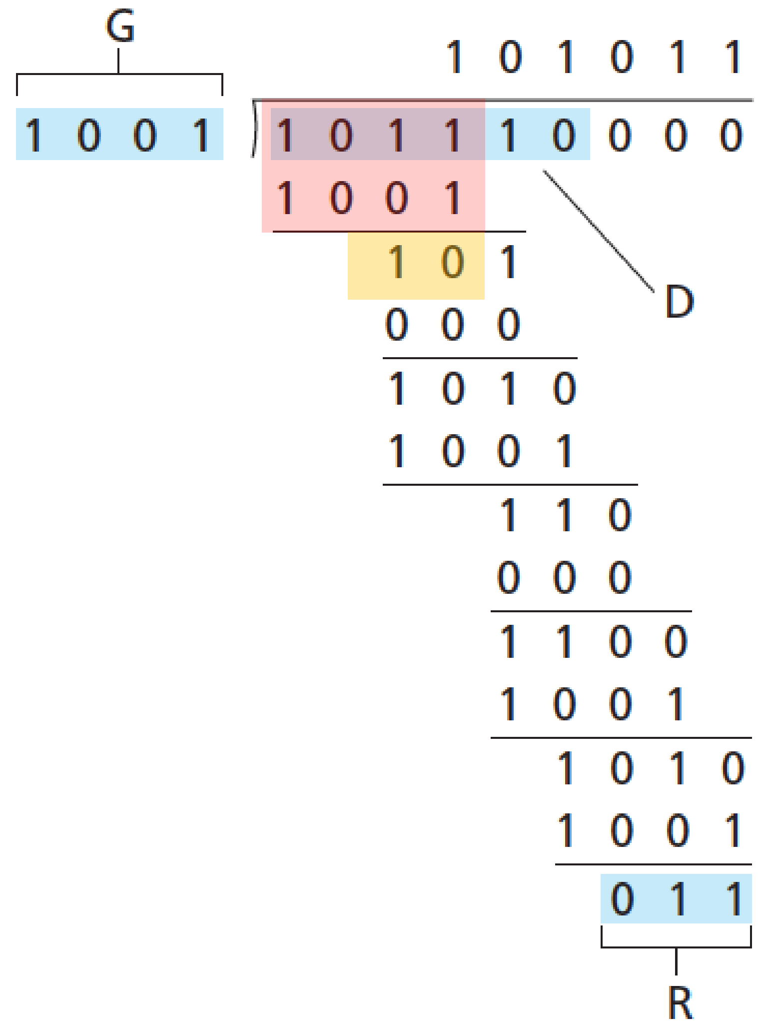
CRC example

- Multiply 1 times 1001 to get 1001



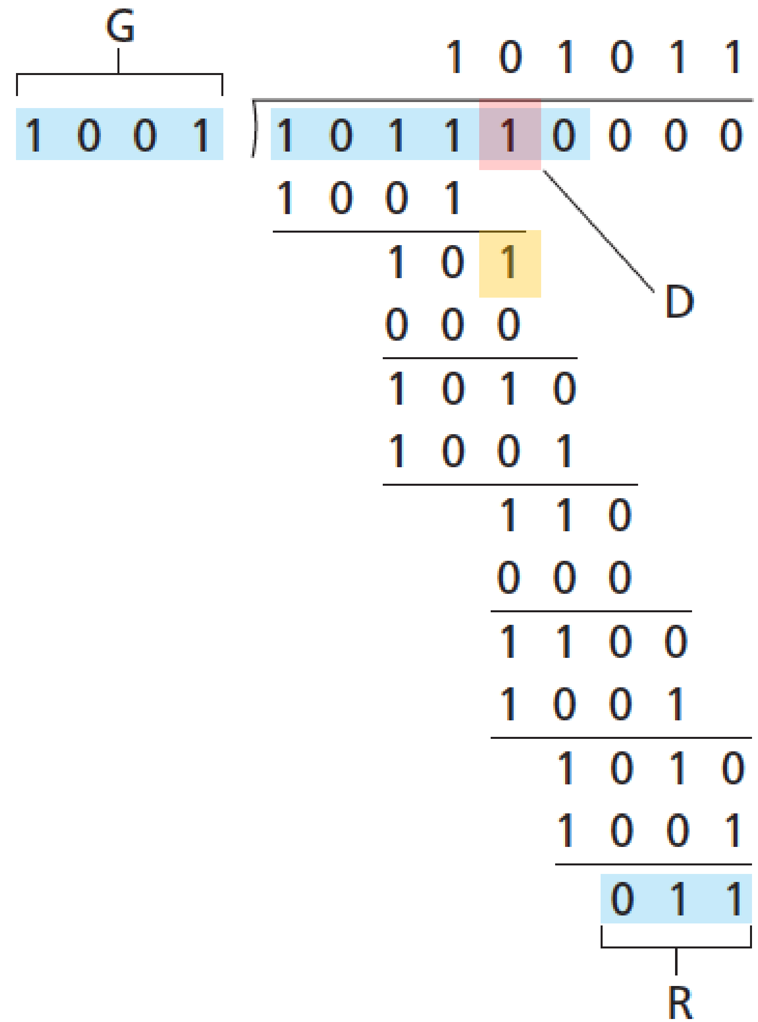
CRC example

- XOR 1011 and 1001 to get 10
  - 1011
    1001
    0010



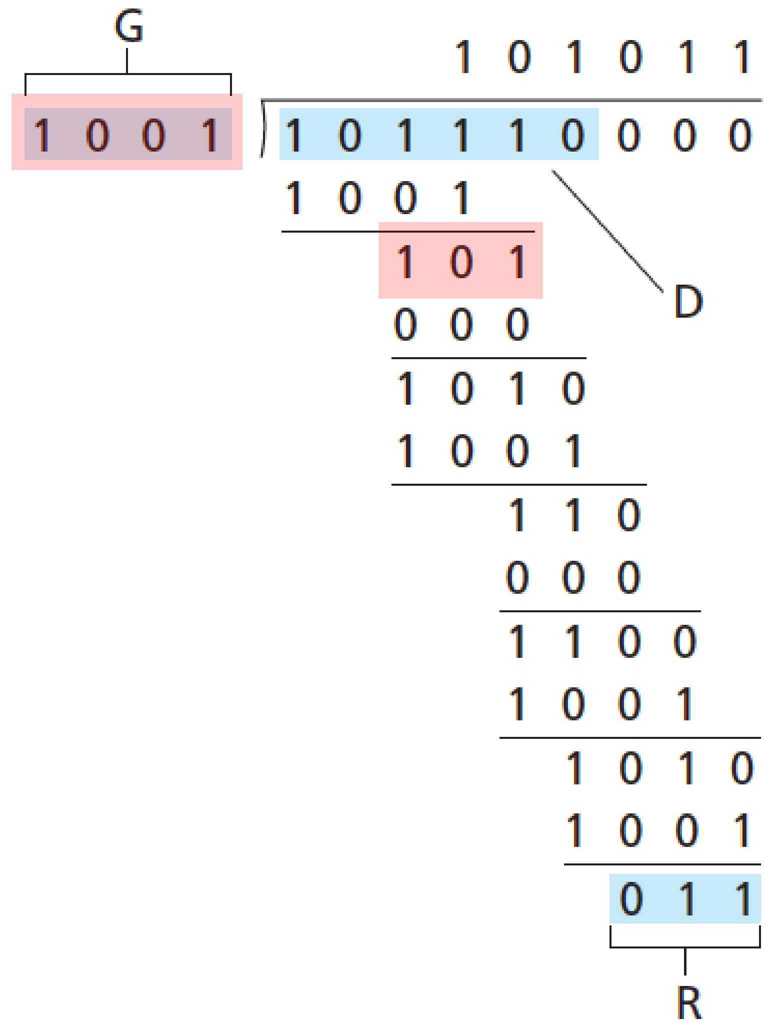
CRC example

- Carry down the 1



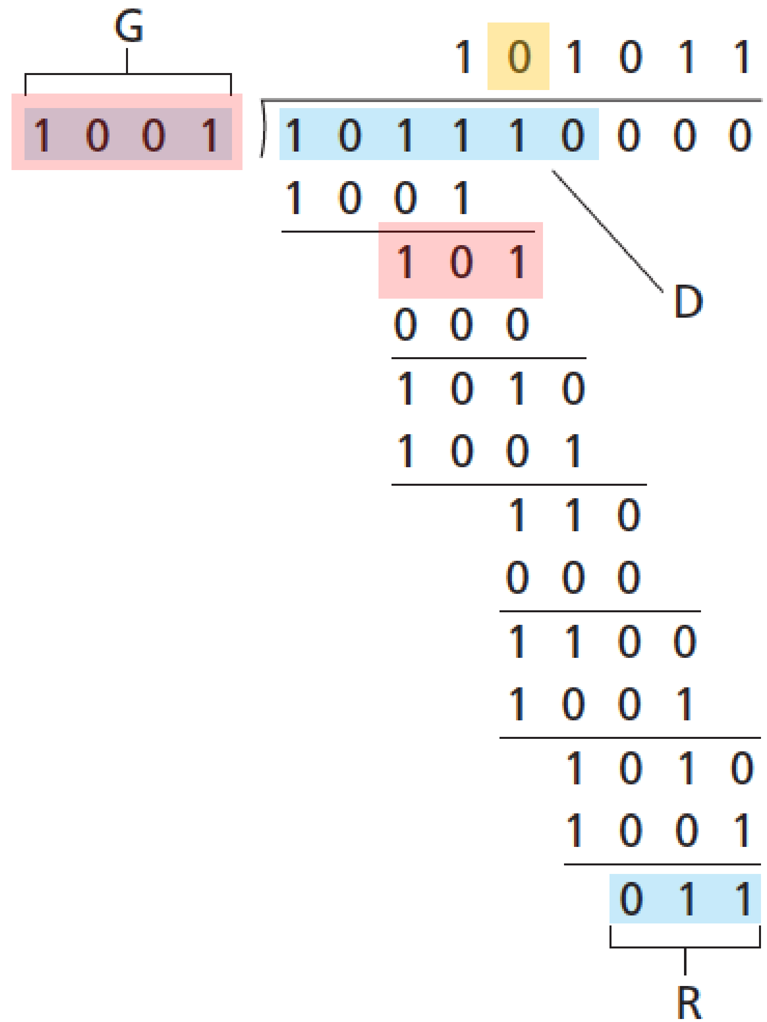
CRC example

- How many times does 1001 go into 101?



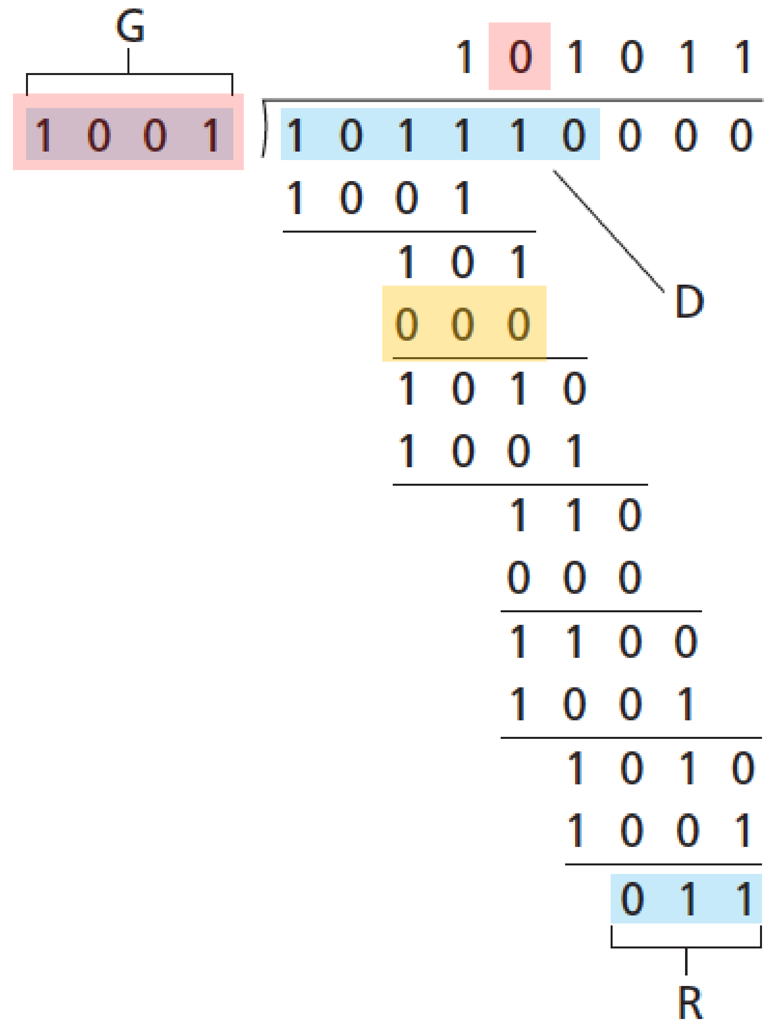
CRC example

- How many times does 1001 go into 101?
- Zero times!



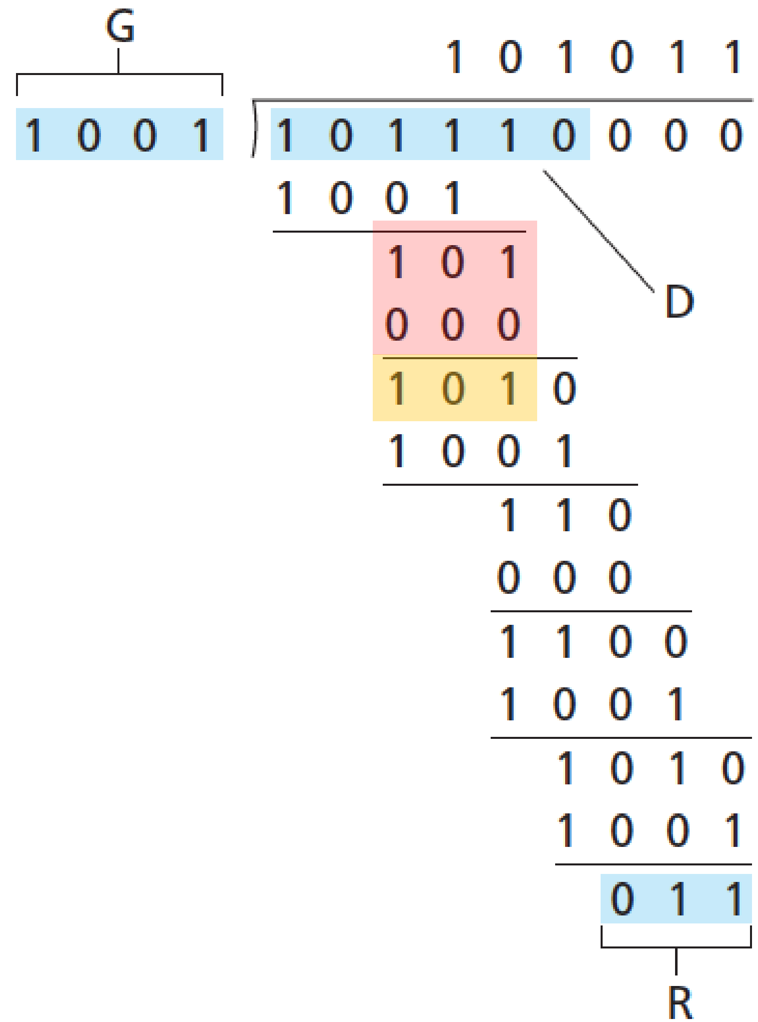
CRC example

- Multiply 0 times 1001 to get 000



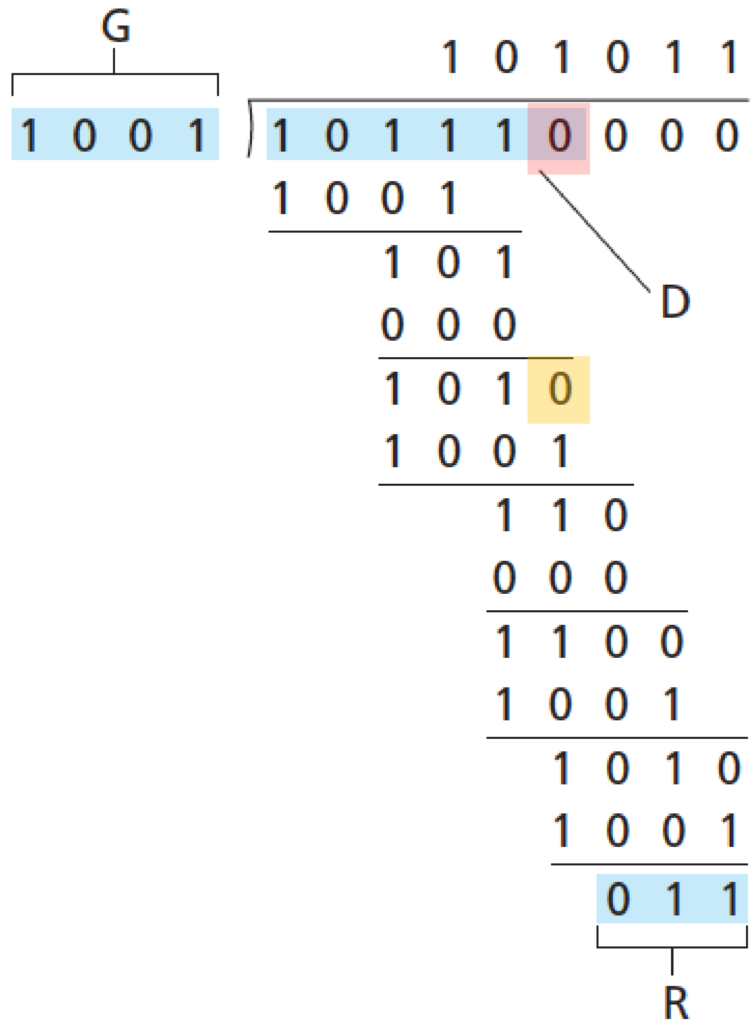
CRC example

- XOR 101 and 000 to get 101
  - 101
    000
    101



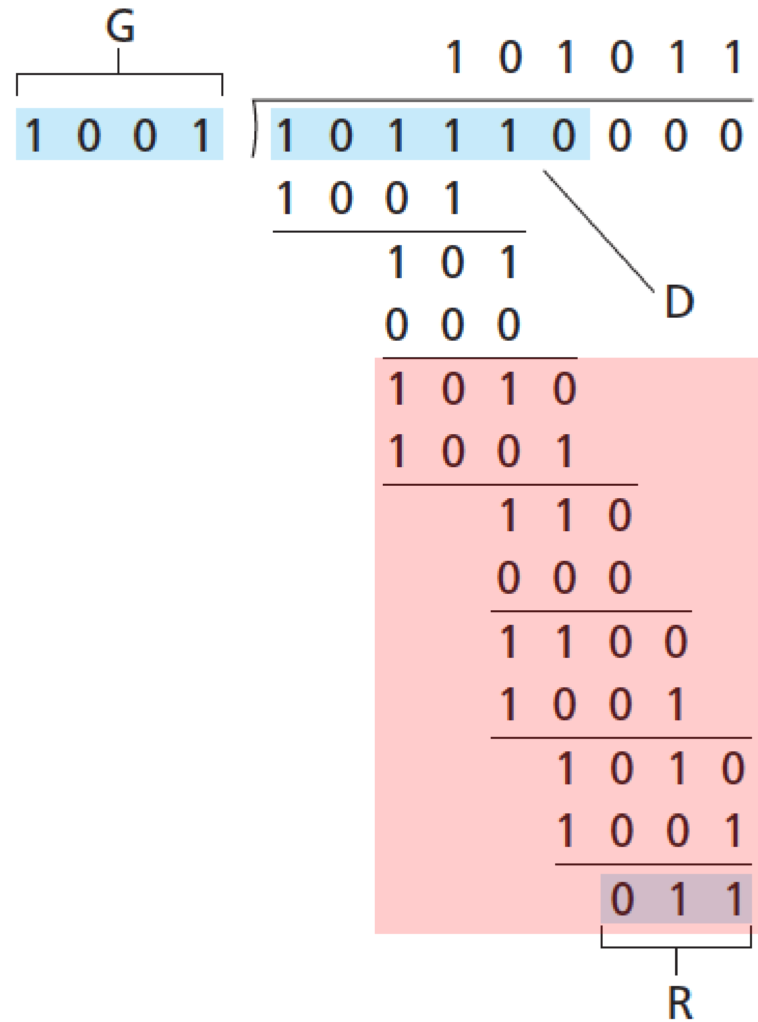
CRC example

- Carry down the 0



CRC example

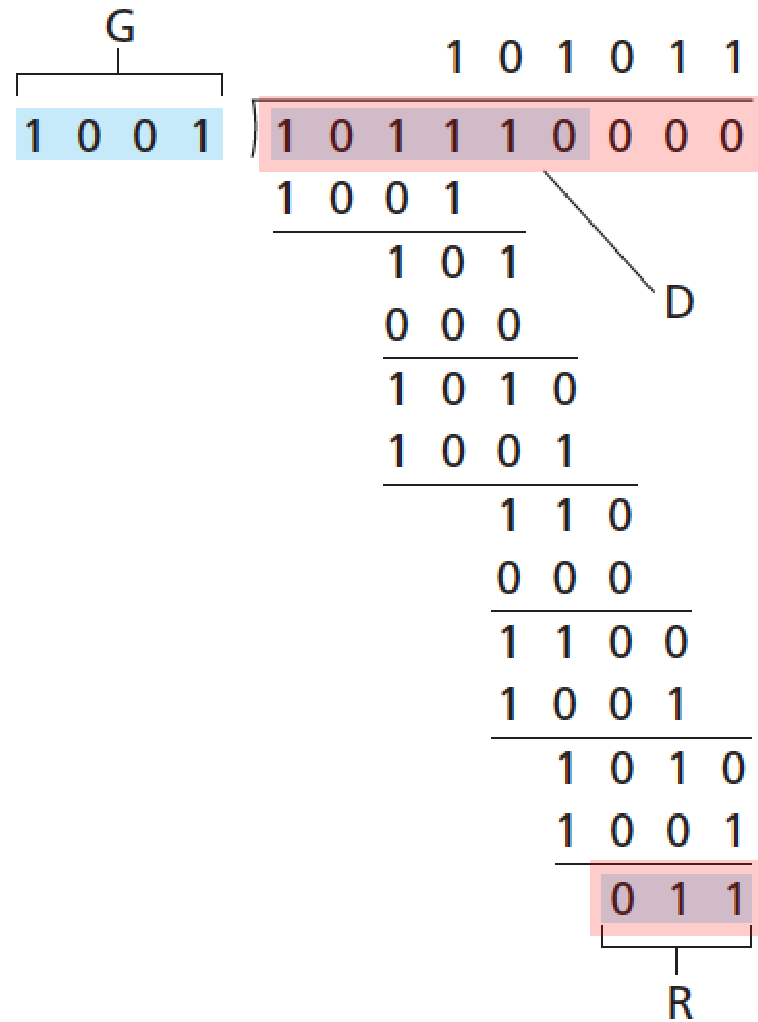
- Repeat……



CRC example

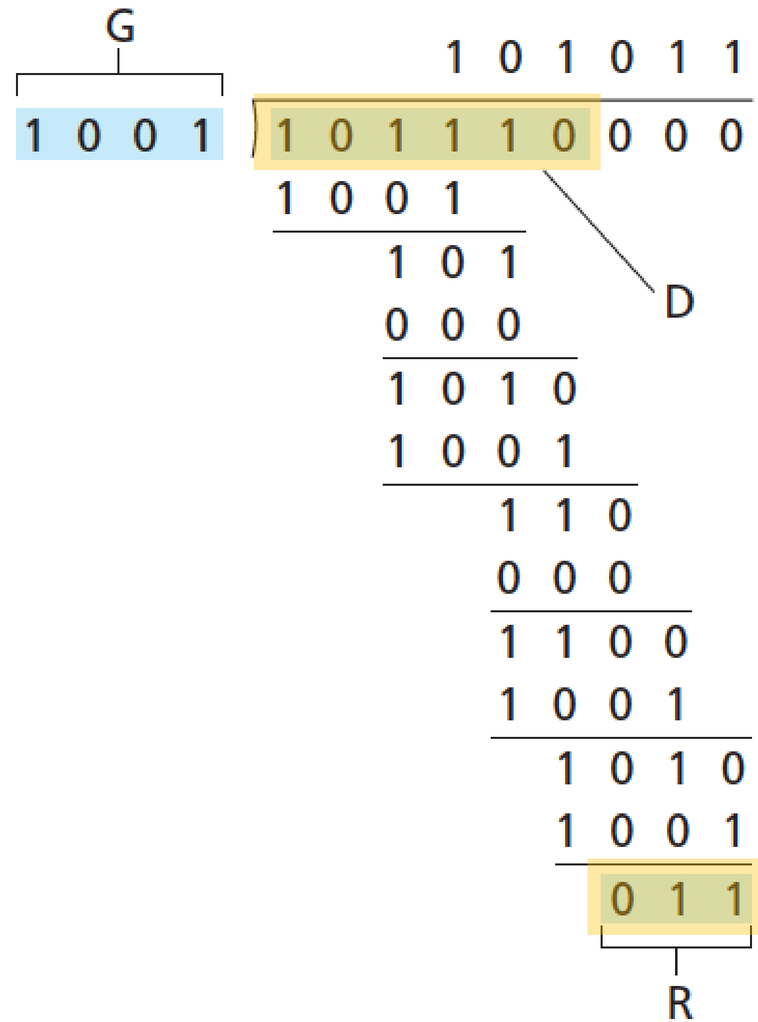
- 3) Replace bit shifted part with remainder

- 101110000
  011 +



CRC example

- 3) Replace bit shifted part with remainder
- 101110000
  011 +
  101110011
- Sender sends
  101110011



CRC example

- Receiver wants to error check
  - 1) Divide received frame by G *(using XOR)*
  - 2) If remainder is 0, no errors!
    If non-0, errors!

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