The Link Layer

COMPSCI 453 Computer Networks
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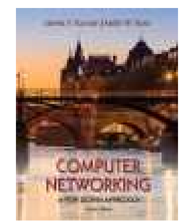
University of Massachusetts

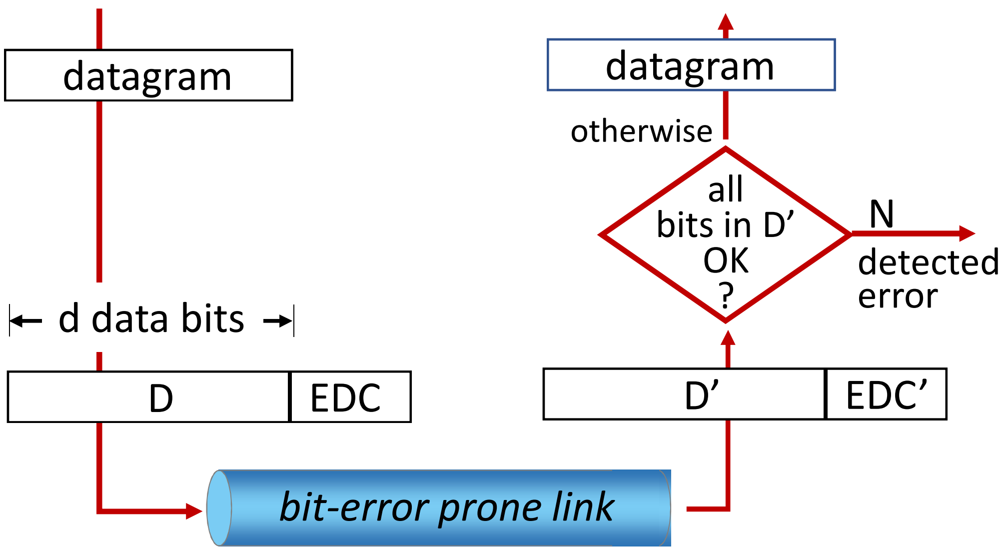
- Introduction to the Link Layer
- **Error-detection and -correction Techniques**
- Multiple Access Links and Protocols
- Switched Local Area Networks
- Link Virtualization: a Network as a Link Layer
- Data Center Networking
- Retrospective: A Day in the Life of a Web Page Request

Class textbook:
Computer Networking: A Top-Down Approach (8th ed.)
J.F. Kurose, K.W. Ross
Pearson, 2020
http://gaia.cs.umass.edu/kurose_ross



Error detection

EDC: error detection and correction bits (e.g., 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

0111000110101011	1

← *d* data bits → | parity bit

Even parity: set parity bit so there is an even number of 1's

At receiver:

- compute parity of *d+1* received bits, if not even, then error detected
- can detect odd number of bit flips

Two-D parity:

row parity →

column parity ↓

$d_{1,1}$	. . .	$d_{1,j}$		$d_{1,j+1}$
$d_{2,1}$	. . .	$d_{2,j}$		$d_{2,j+1}$
. . .	. . .	. . .		. . .
$d_{i,1}$	. . .	$d_{i,j}$		$d_{i,j+1}$
$d_{i+1,1}$	. . .	$d_{i+1,j}$		$d_{i+1,j+1}$

- detect two-bit errors
- detect *and correct* single bit errors without retransmission!

no errors:

1 0 1 0 1	1
1 1 1 1 0	0
0 1 1 1 0	1
1 0 1 0 1	0

detected and correctable single-bit error:

1 0 1 0 1	1
1 0 1 1 0	0
0 1 1 1 0	1
1 0 1 0 1	0

parity error (row 2)

parity error (column 2)

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

Internet checksum (review, see section 3.3)

Goal: detect errors (*i.e.,* flipped bits) in transmitted segment

sender:

- treat contents of UDP segment (including UDP header fields and IP addresses) as sequence of 16-bit integers
- checksum: addition (one's complement sum) of segment content
- checksum value put into UDP checksum field

receiver:

- compute checksum of received segment
- check if computed checksum equals checksum field value:
  - not equal - error detected
  - equal - no error detected. *But maybe errors nonetheless?* More later ….

Cyclic Redundancy Check (CRC)

- more powerful error-detection coding
- D: data bits (given, think of these as a binary number)
- G: bit pattern (generator), of *r+1* bits (given, specified in CRC standard)

r CRC bits

← d data bits →

D	R

bits to send

<D,R> = D $*$ 2^r XOR R

formula for these bits

sender: compute *r* CRC bits, R, such that <D,R> *exactly* divisible by G (mod 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)

Cyclic Redundancy Check (CRC): example

Sender wants to compute R such that:

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

... or equivalently (XOR R both sides):

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

... which says:

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

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

algorithm for computing R

```
G                       1 0 1 0 1 1
                    ___________________
1 0 0 1            ) 1 0 1 1 1 0 0 0 0
                     1 0 0 1
                         1 0 1
                         0 0 0
                         1 0 1 0
                         1 0 0 1
                             1 1 0
                             0 0 0
                             1 1 0 0
                             1 0 0 1
                               1 0 1 0
                               1 0 0 1
                                 0 1 1
                                   R
```

$D * 2^r$ (here, r=3)

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