

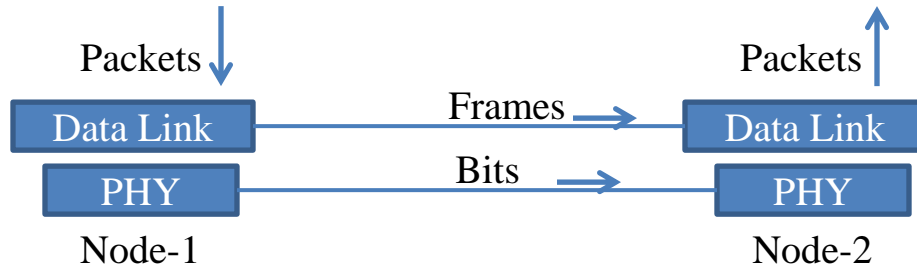
Error Control (An Overview)

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Recap

- Frame-by-Frame next-hop delivery
- Focus on Error Control
 - Error Detection and recovery



Error Detection

- What cause errors?
 - Distortion of signals due to frequency dependant attenuation, noise (PHY layer)
 - Random single-bit vs Bursty errors
- Why detect errors?
 - Data fidelity, prevent wastage of resources

What next?

- After Detection:
 - Drop Frame
 - Higher layers (e.g TCP) will recover or few losses dont hurt applications (e.g. audio)
 - Recover Frame
 - Error Correction: Frame carries enough information to correct errors
 - Retransmission: Receiver signals sender on error, sender retransmits the frame

Error correction vs Retransmission

- Error correction requires more redundant bits per frame than error detection
 - Redundancy bits are sent all the time (every frame)
- Retransmission requires another copy to be transmitted
 - Copy sent only on error

Usage

- Error correction useful when
 - Error rate is high (e.g. wireless)
 - Cost (e.g. latency) of retransmission is too high (e.g. satellite link)

Framework

- Add redundant information to a frame to detect or correct errors
- At Sender: Add **k** bits of redundant data to a **m** bit message
 - k derived from original message through some algorithm
- At Receiver: Reapply same algorithm as sender to detect errors; take corrective action if necessary
- Examples:
 - Detection: $k \ll m$; $k = 32$; $m \sim 12,000$ for Ethernet
 - Correction: Code Rate: $m/(m+k)$
 - WiFi code rates range from $1/2$ to $5/6$

Hamming Distance

- Code word: $n=m+k$ bits
- Hamming distance between two codewords:
Number of bits they differ in
 - XOR the two codewords
- Example:
 - Codewords: 01110110, 00011101
 - Distance is 5

Hamming Distance of a Code

- Number of possible code words is 2^n
- Legal code words = 2^m (determined by the algorithm)
- Among the list of legal code words, find the smallest hamming distance between two code words
 - This is the hamming distance of a code (=d)

Rules

- The error detection/correction capabilities are a function of the code's hamming distance
- Error Detection: Can detect up to $d-1$ errors
 - To change one codeword to another require at least d bit changes
- Error Correction: Can correct up to $(d-1)/2$ errors
 - The received codeword (in error) is still closer to the original codeword than any other codeword

Example

- Repetition code
 - $0 \rightarrow 000; 1 \rightarrow 111$
 - $m=1, k=2; n=3$
 - Hamming distance is 3, code rate is $1/3$
- Can detect up to 2 errors and correct up to 1 error

Design Considerations of a Code

- Reduce k to achieve high code rate
- For given values of n and k , maximize d
- Easy encoding and decoding
 - Minimal memory and processing time

Focus

- Error Detection
- Reliable Transfer (retransmissions)
- ~~• Error Correction~~
 - ~~– E.g. Reed Solomon codes, Convolution codes, Turbo codes~~

Summary

- Important to detect errors in frames
- Error Recovery: FEC or Retransmission
 - Inherent tradeoffs
- Framework (Overview)
 - Hamming distance and error detection/correction capabilities
 - Design considerations
- Going forward: Error detection (in detail)