Previously

- HDLC – High Level Data Link Control
- PPP – Point-to-Point Protocol

Error Detection & Correction

- Error Correction
  - Hamming distance
- Error Detection
  - Parity bits
  - Block Sum Check
  - CRC

Errors

- Occurrence of errors
  - Rare on _____
  - More frequent on _____
- Type of errors
  - Errors generally occur as _____ or _____
  - Burst errors mean that _____ but _____
- Redundant Info is needed to
  - _____
  - _____

Basics

- Frame consists of $n = m + r$ bits
  - m _____
  - r _____
  - There are only _____
- e.g. Parity bit: _____
  - Even parity: _____
  - Odd parity: _____
  - 1001010 → _____(even) or _____ (odd)
  - There are _____
  - We can detect _____
  - No way to _____

Forward Error Correction

- Hamming Distance _____
  _____
  - Determine by _____ 10010100 00000111
  - For example…. 10011110 11001100
- Hamming distance of a code _____
  _____
  - E.g. 00111
- To detect an error of d bits… 01100
  - _____ 10010
- To correct an error of d bits… 11001
  - _____
  - where _____

Single bit correction

- To correct single bit errors…
  - Given 2^m messages, for each message there _____ (Corrupt each bit of the message)
  - $(n+1).2^m \leq 2^n$ _____
  - $(m+r+1) \leq 2^r$ _____
- Hamming codes achieves this lower limit

Hamming codes

- Hamming code achieves this lower limit
- Check bits: 1, 2, 4, 8, … _____
- Data bit indices: 3, 5, 6, 7, 9, 10, 11, … _____
- Check bits are parity bits computed from those data bits whose binary decomposition includes the check bit:

Data bit:	1	2	3	4	5	6	7	8
Data bit index:	3	5	6	7	9	10	11	12
Binary decomposition:	1	1		1	1		1	
	2		2	2		2	2	
		4	4	4				4
					8	8	8	8

- If one check bit is incorrect _____
- If multiple check bits are incorrect _____
- To correct burst errors we change _____
  _____

Hamming code example

ASCII

H	1001000	→
a	1100001	→
m	1101101	→
m	1101101	→
i	1101001	→
n	1101110	→
g	1100111	→

Block Sum Check

- Using a single parity bit the probability of an error not being detected is _____
- To increase this we can use a Block Sum Check
  - Compute parity for _____
  - Probability of an error not being detected is _____

P_K	B_6	B_5	B_4	B_3	B_2	B_1	B_0	
0	0	0	0	0	0	1	0	= STX
1	0	1	0	1	0	0	0	Frame contents
0	1	1	0	0	0	1	0	
0	0	1	0	0	0	0	0	
1	0	1	0	1	1	0	1	
0	1	0	0	0	0	0	0	
1	1	0	0	0	1	1	1	
1	0	0	0	0	0	1	1	= ETX
1	1	0	0	0	0	0	1	= BCC

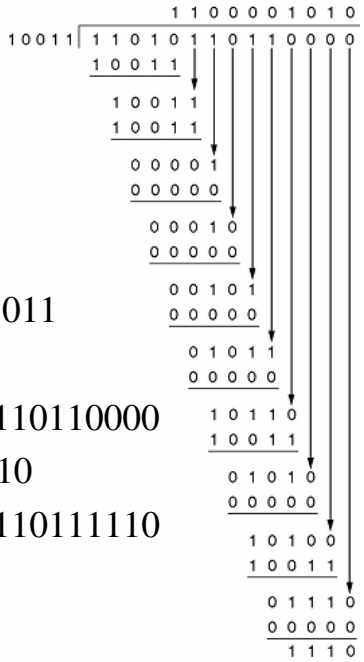
Cyclic Redundancy Check

- Treats the bits in the frame as _____
  - e.g. 110001 = _____
- Determine a Checksum which is
  - Data / Generator Polynomial
  - Checksum is usually _____
  - Generator Polynomial is _____
  - Checksum is referred to as the FCS (_____ _____) or the CRC (_____)
  - Checksum appended _____

Cyclic Redundancy Check

- Generator Polynomials
  - High & low bits must _____
  - $x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x^1 + 1$
  - $x^{16} + x^{15} + x^2 + 1$
- Computing the checksum
  - Append zero bits → $x^r M(x)$ where r _____
  - $x^r M(x)$ / G(x) This division is done modulo 2
  - Subtract the remainder from $x^r M(x)$
- To detect errors
  - Compute _____
  - If zero then _____,
    otherwise _____

Example



- M(x) = 1101011011
- G(x) = 10011
- $x^r M(x)$ = 11010110110000
- Remainder = 1110
- Transmit 11010110111110

CRC Performance

- E(x): _____
- $E(x) = x^i$ _____. This is not divisible by G(x) as long as _____
- $E(x) = x^i + x^j = x^j (x^{i-j} + 1)$ _____. Detectable as long G(x) is not divisible by _____ _____.
  - E.g. $x^{15}+x^{14}+1$
- To catch all Odd errors we _____.
- Burst errors
  - Catch all errors _____ except _____
  - Probability (Long errors are unnoticed) = _____

Exercise

- Given a message 100110111010 and a generator polynomial $(x^4 + x^3 + x^1 + 1)$ compute the CRC.

- Also, what errors can this CRC detect?

  _____
  _____