CS425: Computer Networks Homework-2

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1. For running the program, type the following command in the terminal
   `$ python main.py`
   This program uses `random` library for random string generation.

   Enter the data block and CRC pattern, when prompted.
   ```
   Enter Data block: 11100011
   Enter CRC pattern: 10011
   ```

   After this, the program will execute all the segments of the question. Two sample outputs are shown below.

sample test output 1

```
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Enter Data block: 11100011
Enter CRC pattern: 10011
The encoded frame is:  111000110110

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Message generated:  1100101111
CRC pattern:  110101
The encoded frame is:  110010111100111

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Error pattern:    101111001001001
Erroneous frame:  011101110101110
Correct frame:    110010111100111

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remainder:  00000
No error detected, frame accepted

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```

sample test output 2

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Enter Data block: 10010011011
Enter CRC pattern: 10011
The encoded frame is:  100100110111100

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Message generated:  0011101010
CRC pattern:  110101
The encoded frame is:  001110101011100

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Error pattern:    010000000101011
Erroneous frame:  011110101110111
Correct frame:    001110101011100

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remainder:  10011
Error detected, frame rejected

------------------
```

2. In the Go-back-N ARQ mechanism using k-bit sequence numbers, the window size is limited to 2^k-1, instead of 2^k to avoid confusion from the RR (receive ready) sent by the receiver to the transmitter. For k bits, the frames received are in cyclic order from 0 to 2^k-1, that is, the size of this set is 2^k. If the window has been of size 2^k, and the receiver sends an RRx, where the frames transmitted were: x, x+1, … 2^k-1, 0 ,1, … , x-1, there are two interpretations of this RRx
    a) All the frames have been received and the receiver is ready for the upcoming x frame.
    b) All the frames were lost and the receiver is asking to resend the first x frame.

    These conflicts can be resolved by reducing the window size to 2^k-1.

3. The maximum window size that can be used in the Selective-Reject ARQ mechanism that uses k-bit sequence numbers is 2^{k-1}. This is done to remove the chances of overlap in between the sending and receiving window as the receiver accepts out-of-order packets. Let the window size of sender's end and receiver's end be W_s and W_r respectively. We know that $W_s = W_r = X$ and $W_s + W_r \leq 2^k$.
$\therefore\ 2X \leq 2^k \Rightarrow X \leq 2^{k-1}$.

4. Given:
   Data rate (r) = 4 kbps
   Propagation delay (t_{prop}) = 20 ms
   Efficiency (U) ≥ 50%
   U = $\frac{1}{1+2a} \geq \frac{1}{2}$
   $\Rightarrow a = \frac{t_{prop}}{t_{frame}} \leq \frac{1}{2}$
   $\Rightarrow t_{frame} \geq 40ms$
   $t_{frame} = \frac{L_{frame}}{r} \geq 40ms$
   $L_{frame} \geq 160\ b$
   Frame sizes ∈ $[160\ bits,\ \infty)$

5. Number of characters in the frame = 1
   Number of bits in one character = 4
   Total bits in the frame = 1*4 = 4
   Probability of bit error (P_b) = 10^{-3}
   a) **probability that the received frame contains no errors**
      $P_{no\ errors} = (1 - P_b)^4$
      $\Rightarrow P_{no\ errors} = (1 - 10^{-3})^4 = 0.996$
   b) **probability that the received frame contains at least one error**
      $P_{at\ least\ 1\ error} = 1 - P_{no\ errors}$
      $= 1 - 0.996$
      $= 0.004$
   c) **Now assume that one parity bit is added. What is the probability that the frame is received with errors that are not detected?**
      The error will not be detected if the message bits are changed according to the parity bit
      Case 1: error in 2 bits, 2 correct bits and correct parity bit
      $P_1 = \frac{4!}{2!.2!} * (P_b)^2.(1 - P_b)^2.(1 - P_b) = 6 * 10^{-6} * (1 - 10^{-3})^3 = 5.982 * 10^{-6}$

      Case 2: error in 4 bits, correct parity bit
      $P_2 = \frac{4!}{4!} * (P_b)^4.(1 - P_b) = 10^{-12} * (1 - 10^{-3}) = 9.99 * 10^{-13}$
      Case 3: error in 1 bit, 3 correct bits and wrong parity bit
      $P_3 = \frac{4!}{1!.3!} * (P_b)^1.(1 - P_b)^3.P_b = 4 * 10^{-6} * (1 - 10^{-3})^3 = 3.988 * 10^{-6}$

      Case 4: error in 3 bits, 1 correct bit and wrong parity bit
      $P_4 = \frac{4!}{3!.1!} * (P_b)^3.(1 - P_b).P_b = 4 * 10^{-12} * (1 - 10^{-3}) = 39.96 * 10^{-13}$
      Total probability $P_{no\ detect}$ = $P_1 + P_2 + P_3 + P_4$
      $= 9.97 * 10^{-6} + 49.95 * 10^{-13}$
      $\approx 9.97 * 10^{-6}$

6. P = 110011
   M = 11100011
   Size of P = 6 bits
   Redundant bits to be added to M = size of P - 1 = 5
   M’ = 1110001100000
   CRC will be the reminder we get after dividing M’ by P

```
           _______________
110011  | 1110001100000 |   10110110
          110011
           —-----
          0010111
           000000
           —-------
           0101111
            110011
            —-------
            0111000
             110011
             —-------
             0010110
              000000
              —-------
              0101100
               110011
               —-------
               0111110
                110011
                 —-------
                0011010
                 000000  =  11010  <= CRC and final signal is 1110001111010
```

7.

   a) $P(X) \ = \ X^4 + X + 1$
      Message: 10010011011
      $\Rightarrow \ M(X) \ = X^{10} + X^7 + X^4 + X^3 + X + 1$
      Length of P = 5 bits
      $\therefore M'(X) \ = X^4(X^{10} + X^7 + X^4 + X^3 + X + 1) = \ X^{14} + X^{11} + X^8 + X^7 + X^5 + X^4$
      CRC will be the remainder R(X) obtained after dividing M’(X) by P(X)

$$
\begin{array}{r|l|l}
X^4 + X + 1 & \overline{X^{14} + X^{11} + X^8 + X^7 + X^5 + X^4} & X^{10} + X^6 + X^4 + X^2 \\
 & X^{14} + X^{11} + X^{10} & \\
 & \text{------------------------------} & \\
 & \quad X^{10} + X^8 + X^7 + X^5 + X^4 & \\
 & \quad X^{10} + X^7 + X^6 & \\
 & \quad \text{--------------------} & \\
 & \qquad X^8 + X^6 + X^5 + X^4 & \\
 & \qquad X^8 + X^5 + X^4 & \\
 & \qquad \text{---------------} & \\
 & \qquad\quad X^6 & \\
 & \qquad\quad X^6 + X^3 + X^2 & \\
 & \qquad\quad \text{-----------} & \\
 & \qquad\qquad X^3 + X^2 & \\
 & \qquad\quad \text{-----------} &
\end{array}
$$

∴ The encoded message is M'(X) + R(X) = $X^{14} + X^{11} + X^8 + X^7 + X^5 + X^4 + X^3 + X^2$
i.e., **100100110111100**

b) Error pattern: 100010000000000
⇒ received bits $M_{received}$: 000110110111100
∴ $M_{received}(X) = X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^3 + X^2$
For error detection, divide $M_{received}(X)$ by $P(X)$
[division on next page]
Remainder = $R_{received}(X) = X^3 + X^2 + X \equiv 1110 \neq 0000$
Hence, error is detected.

$$X^4 + X + 1 \;\left|\; \overline{X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^3 + X^2} \;\right|\; X^7 + X^6 + X^3 + X^2 + X$$

$$\begin{array}{l}
X^{11} + X^8 + X^7 \\
\hline
X^{10} + X^5 + X^4 + X^3 + X^2 \\
X^{10} + X^7 + X^6 \\
\hline
X^7 + X^6 + X^5 + X^4 + X^3 + X^2 \\
X^7 + X^4 + X^3 \\
\hline
X^6 + X^5 + X^2 \\
X^6 + X^3 + X^2 \\
\hline
X^5 + X^3 \\
X^5 + X^2 + X \\
\hline
X^3 + X^2 + X \\
\hline
\end{array}$$

c) Error pattern: 100110000000000

$\Rightarrow$ received bits $M_{received}$: 000010110111100

$\therefore M_{received}(X) = X^{10} + X^8 + X^7 + X^5 + X^4 + X^3 + X^2$

For error detection, divide $M_{received}(X)$ by $P(X)$

[division on next page]

Remainder = $R_{received}(X) = 0 \equiv 0000$

Hence, error is not detected.

$$
\begin{array}{l}
X^4 + X + 1 \;|\; \overline{X^{10} + X^8 + X^7 + X^5 + X^4 + X^3 + X^2} \;|\; X^6 + X^4 + X^2 \\
\qquad\qquad\quad X^{10} + X^7 + X^6 \\
\qquad\qquad\quad \text{---} \\
\qquad\qquad\qquad\quad X^8 + X^6 + X^5 + X^4 + X^3 + X^2 \\
\qquad\qquad\qquad\quad X^8 + X^5 + X^4 \\
\qquad\qquad\qquad\quad \text{-------------------------------} \\
\qquad\qquad\qquad\quad X^6 + X^3 + X^2 \\
\qquad\qquad\qquad\quad X^6 + X^3 + X^2 \\
\qquad\qquad\qquad\quad \text{-------------------------------} \\
\qquad\qquad\qquad\qquad\quad 0 \\
\qquad\qquad\qquad\quad \overline{}
\end{array}
$$