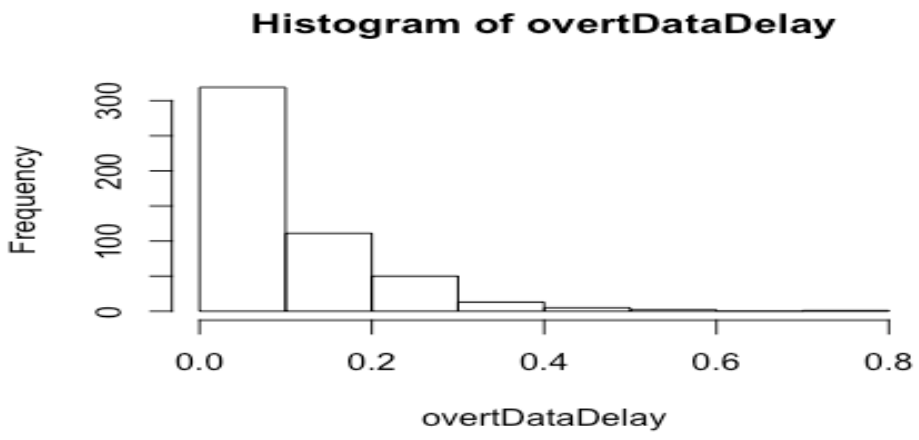
Design

Question #1

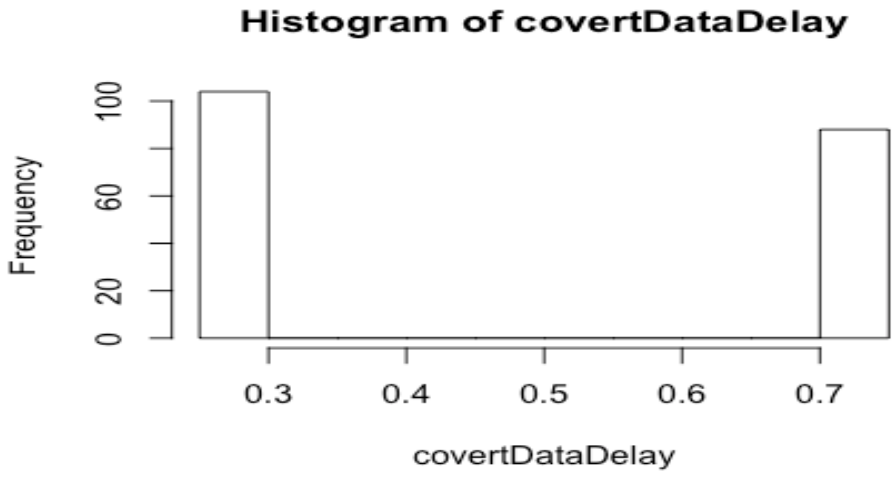
```
overtData <- read.csv(file = "Traffic_data_orig.csv", header = TRUE,sep
= ",")
secretMessage <- "this is a secret message"
messageLen = as.numeric(nchar(secretMessage))

CharToBinary = function(pchar) {
  lhex = charToRaw(pchar)
  lbits = rev(as.numeric(rawToBits(lhex)))
  return(lbits)
}#Converts a character to Binary equivalent

StringToBinary = function(pstr, pstrlen) {
  lbitstream = NULL
  ltemp = NULL
  for (i in 1:pstrlen) {
    ltemp = CharToBinary(substring(pstr,i,i))
    lbitstream <- c(lbitstream,ltemp)
  }
  return(lbitstream)
}#converts a string to Binary vector

#Q1. GENERATING MODIFIED PACKET STREAM
binaryMessage = StringToBinary(secretMessage, messageLen)
lenBinaryMessage = as.numeric(length(binaryMessage))
covertPackets = NULL
timeStream = 0
covertDataDelay = NULL

for (i in 1:lenBinaryMessage) {
  if(binaryMessage[i] == 0){
    timeStream <- timeStream + 0.25
    covertDataDelay <- c(covertDataDelay,0.25)
  }#if bit is 0, delay is 0.25
  else{
    timeStream <- timeStream + 0.75
    covertDataDelay <- c(covertDataDelay,0.75)
  }#if bit is 1, delay is 0.75
  covertPackets <- c(covertPackets,timeStream)

}#loop to generate packet stream from binary message

#Q2. Generating the Histogram
temp = 0 #holds the previous timestamp
overtDataDelay = numeric(dim(overtData)[1])

for( i in 1:dim(overtData)[1])
{
  overtDataDelay[i] = overtData[i,2] - temp
  temp = overtData[i,2]
}

hist(overtDataDelay)
hist(covertDataDelay)
```

Question #2

Overt Packet Delay Histogram



Covert Packet Delay Histogram



Will Eve be suspicious?

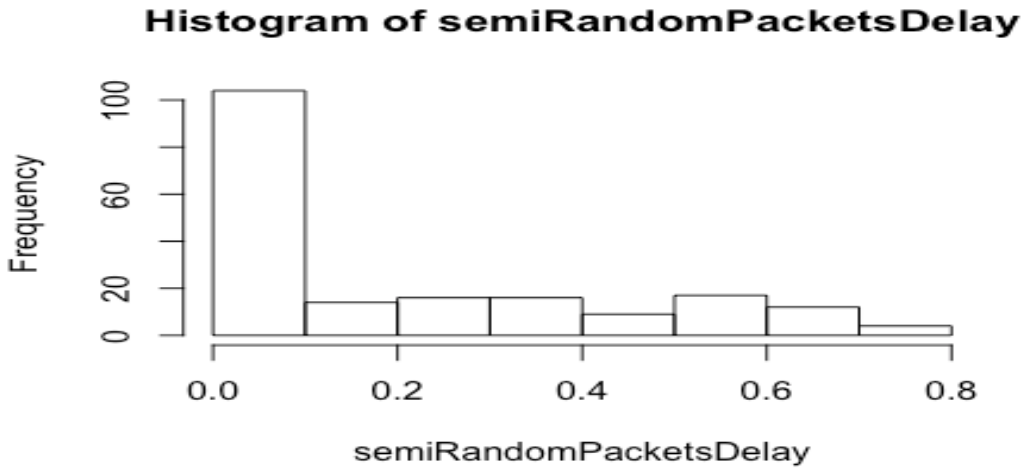
Eve will be suspicious of the 0.75 & 0.25 because it's exactly two unique differences, whereas for the "Overt" data, given to us in the CSV, the histogram looks more like a negative exponential distribution, which is what you would expect of this type of time dependent data

Question #3

```
#Q3
m = median(overtDataDelay)
min = min(overtDataDelay)
max = max(overtDataDelay)

semiRandomPacketsDelay = NULL
semiRandomPackets = NULL
timeStream = 0

for (i in 1:lenBinaryMessage) {
  if(binaryMessage[i] == 0){
    timeLapse = runif(1, min, m)
  }#if bit is 0, delay is 0.25
  else{
    timeLapse = runif(1, m, max)
  }#if bit is 1, delay is 0.75
  timeStream <- timeStream + timeLapse
  semiRandomPacketsDelay <-
c(semiRandomPacketsDelay,timeLapse)
  semiRandomPackets <- c(semiRandomPackets,timeStream)
}#loop to generate packet stream from binary message


hist(semiRandomPacketsDelay)
hist(overtDataDelay)
```

Note: Code is built up on code from question 1

Question #4

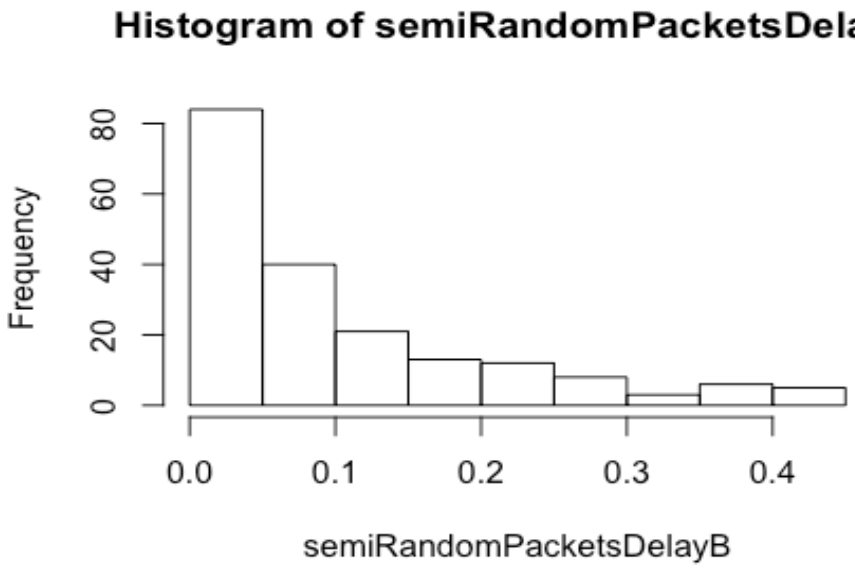


Question #5

1. **Improved Method**
   Since we know that the overt timing delay dataset produces an exponential distribution (pdf), we need to make the covert dataset look as exponential as possible so Eve doesn't suspect us.
   We can use the mean m of the overt data set to generate an exponential distribution (using rexp).
   Alice can base the covert delay times on the generated exponential distribution with some alterations to specify the bit values. The cutoffs for 1s and 0s would be represented as a function of the packet number (the 1st packet of the two packets that the delay is between).

   Encoding Scheme:-
   - Exp(i) - 0.0025 for bit = 1; where i is the packet number and Exp(i) is the density that corresponds to i in an exp(rate = m^-1)
   - Exp(i) + 0.0025 for bit = 0; where i is the packet number and Exp(i) is the density that corresponds to i in an exp(rate = m^-1)

   Assumptions:-
   - Bob knows the distribution of the overt timing dataset (exponential with rate = m)
   - Bob knows the encoding scheme so he can decode the message.



Code

```
     set.seed(1237)
#m = median(overtDataDelay)
#m = quantile(overtDataDelay, probs = c(0.75) ,names=
FALSE)
m = mean(overtDataDelay)
min = min(overtDataDelay)
max = max(overtDataDelay)

semiRandomPacketsDelayB = NULL
semiRandomPacketsB = NULL
timeStream = 0
Nexp <- rexp(1000000000000000, m^-1)

for (i in 1:lenBinaryMessage) {
  if(binaryMessage[i] == 0){
    timelapse = Nexp[i] - 0.0025
    #timeLapse = rexp(1, m)
  }#if bit is 0, delay is 0.25
  else{
    timeLapse = Nexp[i] + 0.0025
    #timeLapse = runif(1, m)
  }#if bit is 1, delay is 0.75
      timeStream <- timeStream + timeLapse
      semiRandomPacketsDelayB <-
c(semiRandomPacketsDelayB,timeLapse)
  semiRandomPacketsB <- c(semiRandomPacketsB,timeStream)
}#loop to generate packet stream from binary message
hist(semiRandomPacketsDelayB)
```

2. If Alice buffers the packets, there will be a moment (in the beginning) when no packets are sent which would disrupt the continuity of the timing channel; this is obviously unrealistic in the case of a Skype call, which is based on real-time interaction. Overall, it would negatively affect the quality of the call, leading Eve to suspicion.
3. If the network modifies the inter packet delay, the message cannot be decoded correctly since the delays are changed and each bit is encoded via delay times. If Bob knows the distribution of the noise within the channel, he can subtract the mean of the noise's distribution from the covert delay times while decoding to get a somewhat accurate message. This method is obviously flawed as it assumes that the semantic integrity of the message isn't critical.

Detection

Step #1

Code

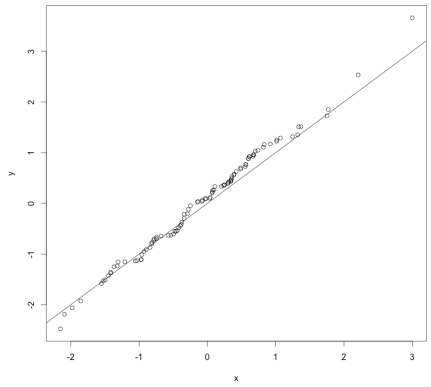
```
x <- rnorm(30,mean = 0,sd = 1)
y <- rnorm(30,mean = 0,sd = 1)
qqplot(x,y, plot.it = TRUE)
abline(0,1)
```

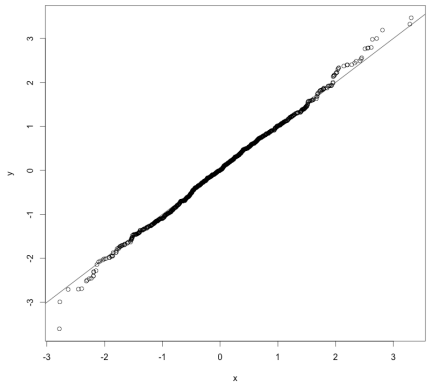
Step #2

Code

```
x <- rnorm(100,mean = 0,sd
= 1)
y <- rnorm(100,mean = 0,sd
= 1)
qqplot(x,y, plot.it = TRUE)
abline(0,1)
```

```
x <- rnorm(1000,mean = 0,sd
= 1)
y <- rnorm(1000,mean = 0,sd
= 1)
qqplot(x,y, plot.it = TRUE)
abline(0,1)
```





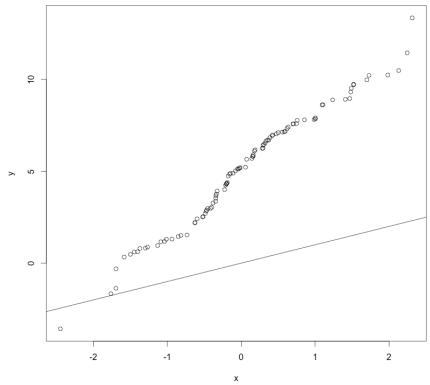
Observation

#It is clear that the shape of the qqplot becomes more linear as n increases.
#This makes sense, as the two distributions are exactly the same.
#The points are dense on the graph between the 1st and 3rd quartiles; they are especially dense around the mean.

Step #3

Code

```
x <- rnorm(100,mean = 0,sd = 1)
y <- rnorm(100,mean = 5,sd = 3)
qqplot(x,y, plot.it = TRUE)
abline(0,1)
```



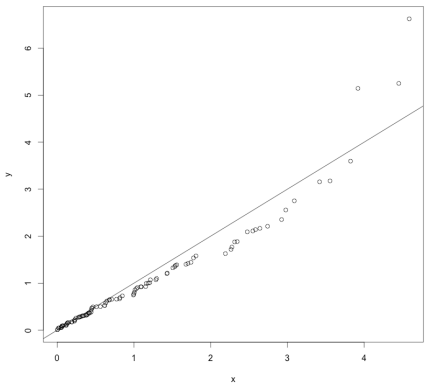
Observation

The shape of this qqplot also appears to be linear, however the slope is much larger than 1 (which would have indicated perfect correlation). Also, the line itself is shifted up so that at x = 0, y = 5. This shows the relationship between the means: the mean of x is 0, and the mean of y is 5. Using this information, we can apply similar rational to the difference in slope. It is caused by the different standard deviations. The slope for y vs x is 3 in our graph, which also describes the ratio of the standard deviations between the two data sets. Despite the fact that the means and standard deviations are different, and that the numerical values for slope and intercepts change because of it, if we normalize y with respect to x, we see that the it does indeed fall on the slope=1 line.

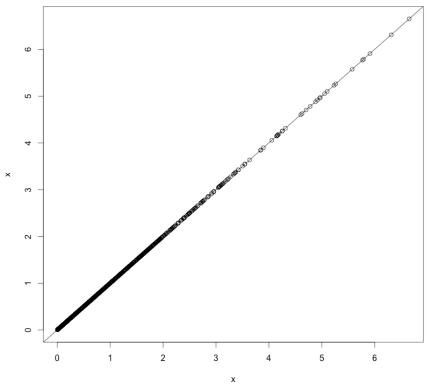
Step #4

Code

```
x <- rexp(100,rate = 1)
y <- rexp(100,rate = 1)
qqplot(x,y, plot.it = TRUE)
abline(0,1)
```




```
x <- rexp(1000,rate = 1)
y <- rexp(1000,rate = 1)
qqplot(x,y, plot.it = TRUE)
abline(0,1)
```



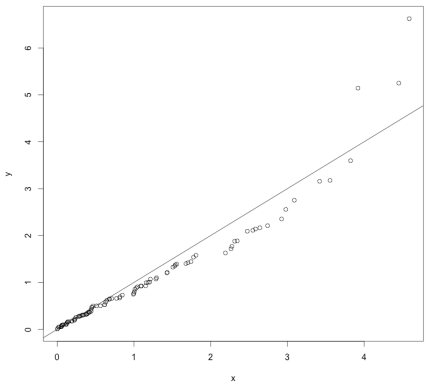
Observation

#It is clear that the shape of the qqplot becomes more linear as n increases.
#This makes sense as the two distributions are exactly the same.
#The points are dense around 1 which makes sense as the mean for an exponencial distribution is (lamda)^-1.

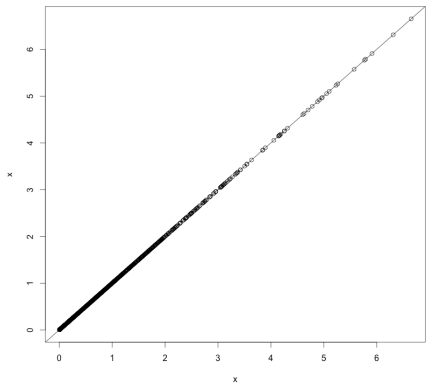
Step #5

Code

```
x <- rnorm(100,mean = 0,sd
= 1)
y <- rexp(100,rate = 1)
qqplot(x,y, plot.it = TRUE)
```



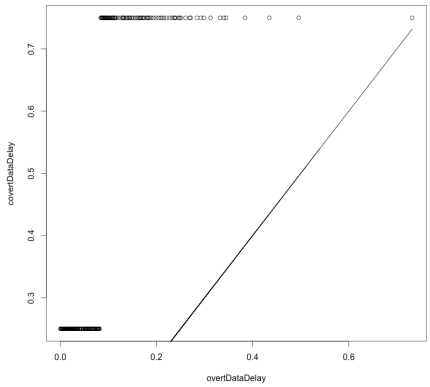
```
x <- rnorm(500,mean = 0,sd
= 1)
y <- rexp(500,rate = 1)
qqplot(x,y, plot.it = TRUE)
abline(0,1)
```



Step #6

Code

```
qqplot(overtDataDelay, covertDataDelay, plot.it = TRUE)
lines(overtDataDelay, overtDataDelay)
```



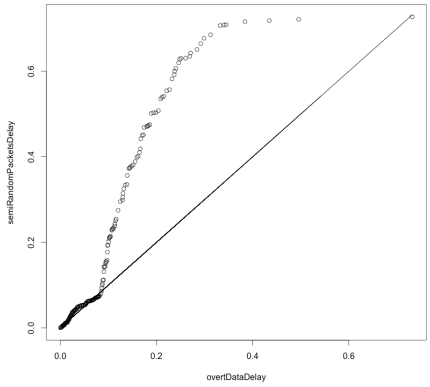
Observation

Clearly, the two distributions are very different and easily distinguishable from each other because the points are nowhere near the slope 1 line. Therefore, Eve will easily detect messages.

Step #7

Code

```
qqplot(overtDataDelay, semiRandomPacketsDelay, plot.it = TRUE)
lines(overtDataDelay,overtDataDelay)
```



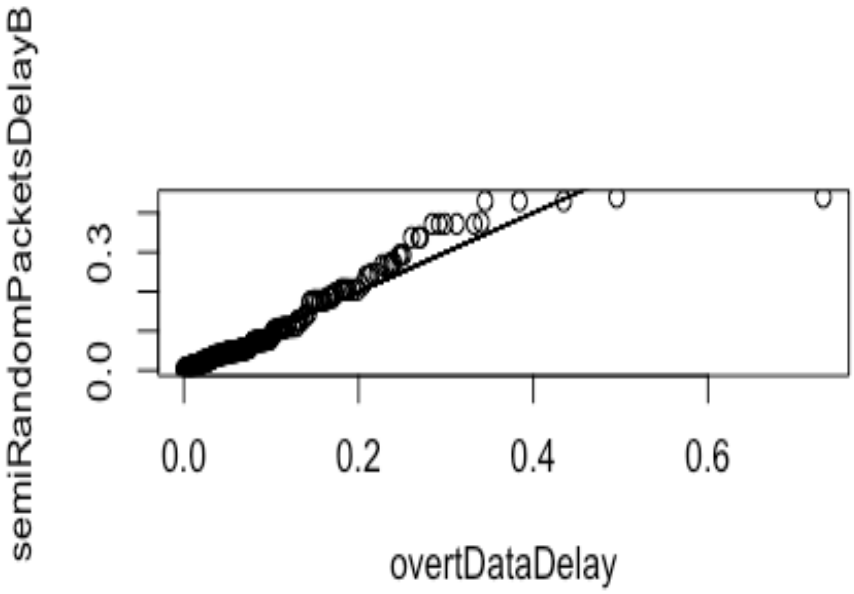
Observation

Although this distribution initially follows closely along the exponential, it quickly diverges. Therefore, Eve will also easily detect this distribution as well. However, it is still better than the method in Step #6

Step #8

Code

```
qqplot(overtDataDelay, semiRandomPacketsDelayB, plot.it = TRUE)
```



Observation
Of the distributions we have developed and tested, this appears to be the best. Eve will probably still be suspicious, but significanly less so and may even careless attribute this to noise, some error in the network, or other confounding variables.

Note: Code is built up on code from question 1

Implementation

1. IPD is exponential with $\lambda = 1$

m	i	P(overflow)	P(underflow)
16	2	0	0.561
	6	0	0.43
	10	0	0.325
	14	0	0.199
	18	0	0
32	2	0.023	0.462
	6	0.017	0.397
	10	0.022	0.32
	14	0.019	0.216
	18	0.02	0.203

2. IPD is uniform

m	i	P(overflow)	P(underflow)
16	2	0	0.591
	6	0	0.565
	10	0	0.514
	14	0	0.37
	18	0	0
32	2	0	0.76
	6	0	0.726
	10	0	0.657
	14	0.019	0.631
	18	0.02	0.584

3. Bounds on Overflow & Underflow Probabilities

Event Definitions:-
i : The number of packets currently in the buffer.

B = Buffer size

P: Overflow:-

- When i = B and the source sends another packet, the source packets cannot be buffered anymore

Q: Underflow:-

- When i = 0 and sender needs to send another packet, the sender cannot send any more packets

A round:-

- Out: If a packet is sent by sender -> i = i – 1 [Gamblers Ruin – "Lose"]
- In: If a packet is received by sender -> i = i + 1 [Gamblers Ruin – "Win"]

Assumptions:-

- Each round is independent from the other rounds
- Packets being sent and received follow same distribution
- Gambler's ruin formula holds

From Gambler's Ruin Formula:-

Let p = P(In) ; q = P(Out)

See attached binder paper and the end for complete answer with bounds for overflow and underflow

4. Propose methods to deal with buffer overflow and underflow.

Dealing with Overflow

- Incorporate a secondary buffer :
  - If the primary butter is full, the source can put packets into the secondary buffer.
- Increase buffer size, B:
  - This would directly decrease the probability of having an overflow as more packets can be accommodated in the buffer

Dealing with Underflow

- Increase i i.e. required # of packets before starting to process
  - This would directly decrease the probability od having an underflow as it forces more packets to be buffered before the sender can send them. So, the sender is less likely to run out of packets while processing.

Dealing with Overflow and Underflow

- Increase B and i (See why above)

Part 5 Code (some functionality build upon previous sections' code)

```
underOrOver = function(m, i, d){
#Buffer vars
B = 20
possible = c(0,1)
binaryMessage = sample(possible, m , replace = TRUE) #Random message of
size m

if (d == 0){
    generatePacketDelays = rexp(m, rate = 1) #Random sequencce of packets
with exp distribution
  }
  else if(d == 1){
```

```
    generatePacketDelays = runif(m, 0, 1) #Random sequencce of packets
with unif distribution
  }

  timePacketStream = 0
  timeLapse = 0
  for(index in 1:m){
    timeLapse = timeLapse + generatePacketDelays[index]
    timePacketStream <- c(timePacketStream, timeLapse)
  }
  timePacketsStream = round(timePacketStream, digits = 3)

  #Simulation for exp dataset

  currentTime = 0

  m   = median(generatePacketDelays) #median of exp dataset
  min = min(generatePacketDelays) #min of exp dataset
  max = max(generatePacketDelays) #max of exp dataset

  semiRandomPacketsDelay = numeric(m+1)
  semiRandomPackets = numeric(m+1)
  senderTimeStream = 0
  senderPackets = NULL
  senderPacketsDelay = numeric(m+1)
  Delay = 0
  start = FALSE
  sourcePacketIndex = 1
  senderMessageIndex = 1
  numUnderFlow = 0 #numeric(1000)
  numOverFlow = 0 #numeric(1000)
  CB = 0
  Buffer = NULL


  for(bit in binaryMessage){
    if(bit == 0){
      Delay = runif(1,min,m)
    }#if bit is 0
    else{
      Delay = runif(1,m,max)
    }#if bit is 1
    senderTimeStream = senderTimeStream + Delay
    senderPackets <- c(senderPackets, senderTimeStream)
    senderPacketsDelay <- c(senderPacketsDelay, Delay)
  }#Precalculates sender delay times
  senderPackets = round(senderPackets, digits = 3)
  #print(paste("PRE-LOOP BUFFER"), Buffer)
```

```
  while(length(binaryMessage) > 0 && sourcePacketIndex <
length(timePacketsStream)){

    if(currentTime >= timePacketStream[sourcePacketIndex] && CB < B){
      #print(paste("ADD T0 BUFFER", currentTime))
      Buffer <- c(Buffer, sourcePacketIndex)
      CB <- length(Buffer)
      sourcePacketIndex = sourcePacketIndex + 1
    }#change sourceindex when reaches currenttime and places source packet
into buffer
    else if(currentTime >= timePacketStream[sourcePacketIndex] && CB >= B)
{
      #print(paste("SKIP BUFFER", currentTime))
      numOverFlow = numOverFlow + 1
      #print(paste("OVERFLOW!!!", currentTime, numOverFlow))
      break
    }#if CB >= B --> overflow

    if(CB == i && start == FALSE){
      #print(paste("START!!", currentTime))
      start= TRUE
    }#if current buffer size is > i, sender can start sending packets

    if((start == TRUE) && (CB > 0) && (senderPackets[senderMessageIndex]
<= currentTime)){
      #print(paste("POP FROM BUFFER!!", currentTime,
senderPackets[senderMessageIndex], Buffer[1]))
      CB = CB - 1 #buffer size decreases by 1
      Buffer = Buffer[-1] #pop off from buffer
      senderMessageIndex = senderMessageIndex + 1 #update message index
      binaryMessage = binaryMessage[-1]
    }#Sender sends a packet
    else if((start == TRUE) && (CB == 0) &&
(senderPackets[senderMessageIndex] <= currentTime)){
      numUnderFlow = numUnderFlow + 1
      #print(paste("UNDERFLOW!!!" , currentTime))
      break
    }#if CB is empty, nothing to send so underflow

    currentTime = currentTime + 0.001 #update current time
  }

   return(c(numOverFlow, numUnderFlow))
}


distribution = c(0,1) #0 for exponential, 1 for uniform
mArr = c(16,32)
i = c (2,6,10,14,18)
```

```
for(D in distribution){
  if(D == 0){
    print(paste("Exponential :"))
  }
  if(D ==1) {
    print(paste("Uniform:     "))
  }
  for (M in mArr){
    print(paste("    M: " , M))
    for (I in i){
      print(paste("        I: ", I))
      over = 0
      under = 0
      for(s in 1:1000){
        #print(s)
        A = underOrOver(M,I, D)
        over = over + A[1]
        under = under + A[2]
      }
      over = over/1000
      under = under/1000
      print(paste("            overflow probability:  ", over))
      print(paste("            underflow probability: ", under))
    }
  }
}
```