Network Security

CMPS-485

Course Project-Phase 3

Deadline: 26th April 2022

Project Title: Performance comparison of state of art of block and stream ciphers over TCP/UDP protocol for different types of wired/wireless networks and applications.

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Abstract

Network security is increasing as the globe progresses to a more sophisticated stage with new technologies and inventions such as Artificial Intelligence (AI), Internet of Things (IoT), and so on. The significance of network security is that it protects a person from data theft, data loss, or hamper data. Cryptography is critical in ensuring the security of communication over the network. Encryption in cryptography occurs in two ways, depending on how plaintext is handled. The goal is of comparing the state of the art of block and stream cipher performance is to better understand how they are utilized to transmit data over the network and to investigate the various faults that cause differences in the transmitted data. Changes in message bits caused by the message being transmitted through wired or wireless media, as well as their impact on the original message, is to be analyzed. In terms of security based on continuous data encryption, stream ciphers have proven to be more efficient than block ciphers in terms of fault tolerance, although block cipher is more secure than stream ciphers.

I. INTRODUCTION

Cryptography has been used around the world since thousands of years with the goal to provide a safer transmission of messages. The message sent is Plaintext and the confidential message is the ciphertext [1]. With the beginning of encryption in ancient times utilizing crude methods, to today's Quantum computer encryption techniques, encryption or secrecy were not a new phenomenon since the dawn of time [2]. An enciphering transformation takes place that converts the plaintext into the ciphertext. There are two ways in which the plaintext is processed that is block ciphers or stream ciphers. The input is processed one block of plaintext at a time with block cipher, whereas stream cipher processes input elements constantly and produces one output at a time [3][4]. These types of ciphers provide a real time operation, as entire dataset is not delivered before decryption starts occurring [2].

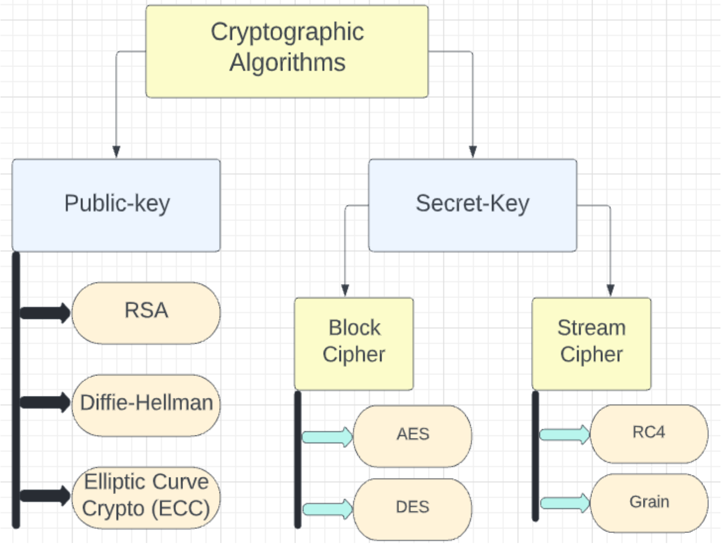


Figure 1 – Classification of Cryptographic Algorithms [5]

I.1) Project Goals and Objectives

The project's goal is to compare and build mechanisms for different types of wired and wireless networks that use block cipher and stream cipher over TCP or UDP protocol. TCP is a more dependable approach than UDP since data is transferred from the transmitter to the receiver without loss. Retransmissions in the TCP protocol offers to give the best performance takes more time than a UDP protocol. Errors in the output (i.e., image) will provide a quick indication of the performance of the block and stream ciphers over a specific protocol. The predicted outcome is for the stream to be far more bearable to errors than block ciphers. The project will also implement these mechanisms to show the error comparison over block cipher using AES with EBC and stream ciphers like RC4 to compare their performance on a UDP protocol using Java / Python programming language.

II. PROJECT DESCRIPTION

A. Project Architecture – Individual Building blocks for the System

1) Block Cipher- AES (ECB Mode)

The Advanced Encryption Standard (AES) is an unbreakable symmetric encryption that uses a single key for both encryption and decryption. Using the most advanced technologies, breaking into the weakest form of AES would take billions of years. [2]. AES uses block cipher processing of the plaintext. Usually, these blocks are of fixed 128 bits size. The key length of different bit sizes such as 128 bits,192 bits, 256 bits results different number of keys.

Bit Width	**Possible Number of Keys**	**Number of Rounds**
128 bits	2^{128}	10
192 bits	2^{192}	12
256 bits	2^{256}	14

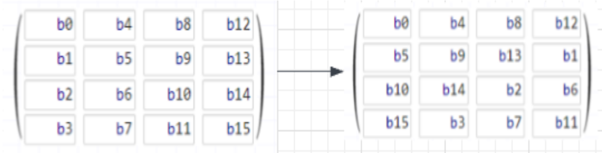
Table 1 – Popular Bit Widths and their key size [2]

Steps used in AES [2]:

1) **Key Expansion –** key scheduling algorithm is used to generate keys
2) **Initial Round key addition –** Initial state of each byte is combined with block of round key.
3) **Round Step – (9, 11 or 13 times)**

i) **Sub Byte Step** – Substitution of bytes according to a table

ii) **Shift Rows Step** – Last three rows are cyclically by 1,2, or 3 steps



$$\begin{pmatrix} b0 & b4 & b8 & b12 \\ b1 & b5 & b9 & b13 \\ b2 & b6 & b10 & b14 \\ b3 & b7 & b11 & b15 \end{pmatrix} \longrightarrow \begin{pmatrix} b0 & b4 & b8 & b12 \\ b5 & b9 & b13 & b1 \\ b10 & b14 & b2 & b6 \\ b15 & b3 & b7 & b11 \end{pmatrix}$$

Figure 2- Shift Row Step [2]

iii) **Mix Columns Step** – Combinations through multiplications of four bytes in every column

iv) **Add Round Key Step**

4) **Last Round –** Takes place once and includes Sub Bytes, Shift Rows, and Add Round key.

These steps together lead to the formation of a ciphertext block that is AES encrypted.

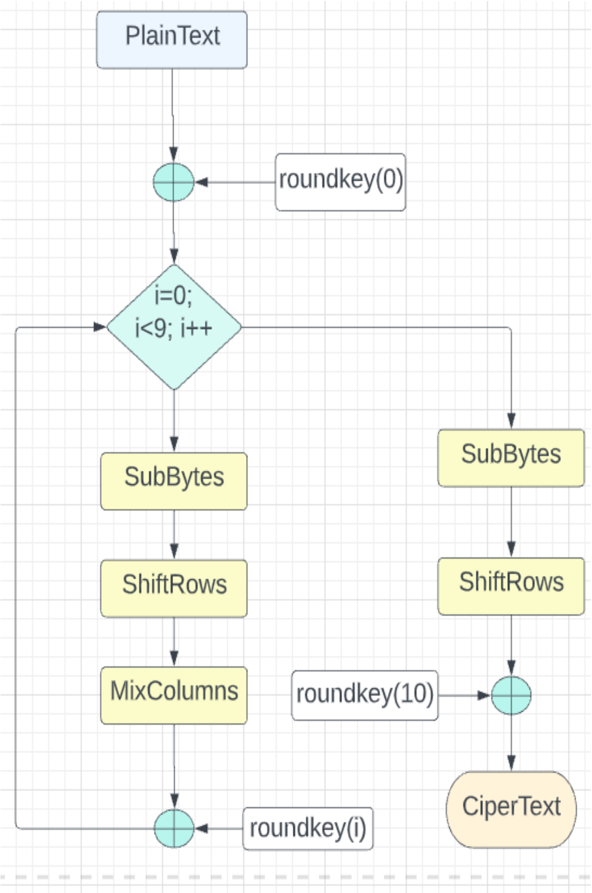


Figure 3 - Overview of AES Algorithm [10]

Electronic Cipher Book (ECB) Mode

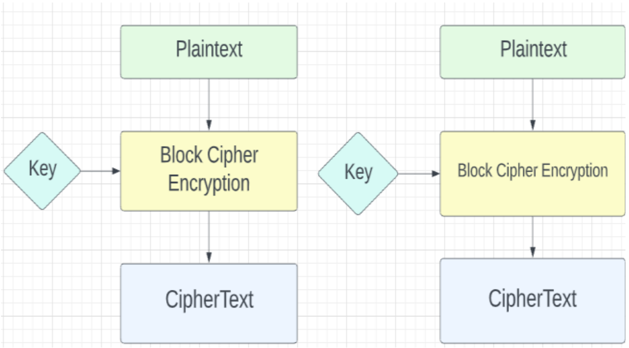


Figure 4- Block Cipher ECB Mode [11]

Each block of plaintext is processed using an encryption with key to produce a ciphertext. An Error in a single plaintext will not affect other blocks as it is not a chaining mode.

Cipher-Block Chaining (CBC) Mode

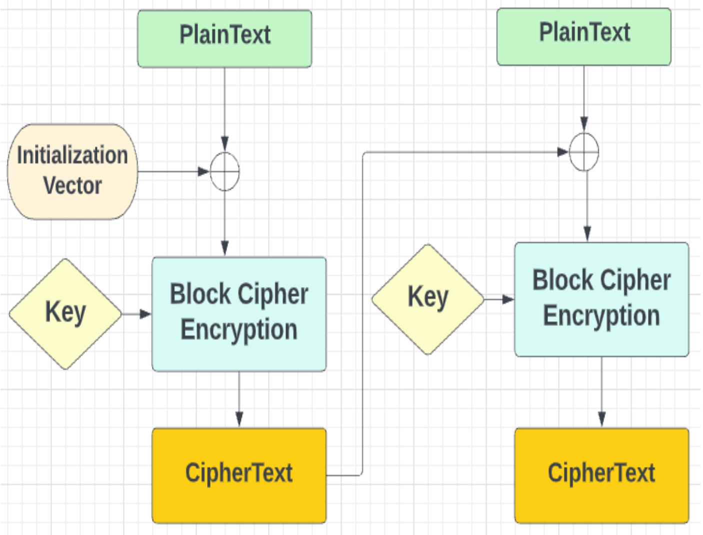


Figure 5- Block Cipher CBC Mode

Cipher Block Chaining (CBC) is a block cipher operating mechanism. Each plaintext block is processed and encrypted, with the cipher key applied to the entire block. Cipher block chaining employs a fixed-length Initialization Vector (IV). This mode uses chaining mode; therefore, the following block is encrypted using the preceding cipher text block, except for the first round, which is XORed with the Initialization vector (IV) to produce the first ciphertext.

Stream Cipher - RC4 Cipher

RC4 is one of the most widely used stream cipher which involves byte level manipulations; hence it is ideal for faster encryption.

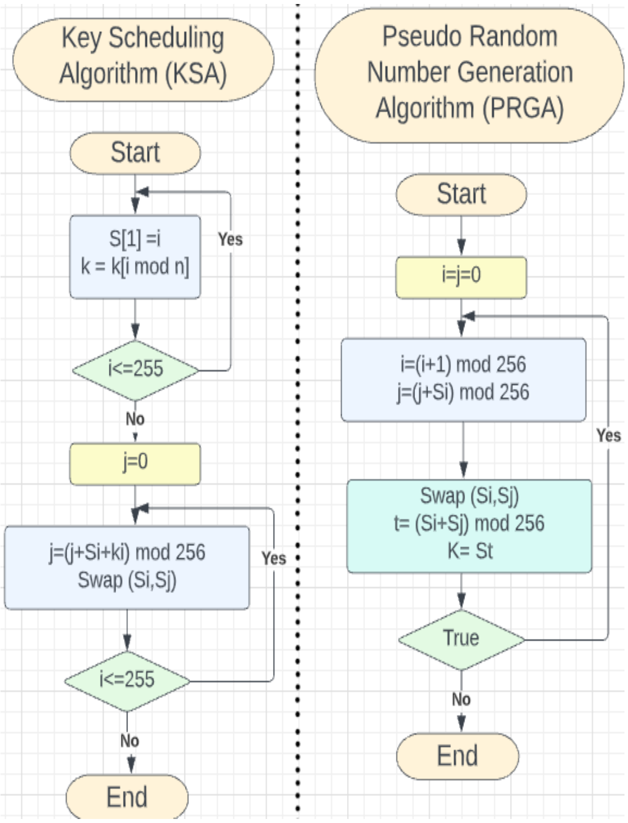


Figure 6-RC4 Stream Cipher [9]

Figure 6 shows the steps implemented by the RC4 Algorithm to produce the output of cipher stream. Stream ciphers deal with individual bits such as the case here in RC4 where individual bits are XORed and processed to give an output bitstream. Figure 7 shows that S Array and T Array that is permutes by Key Scheduling Algorithm (KSA) and Pseudo Random Number Generation Algorithms (PRGA) to produce a key stream to XOR with the plaintext to produce a ciphertext. The objective is to produce a stream of ciphers.

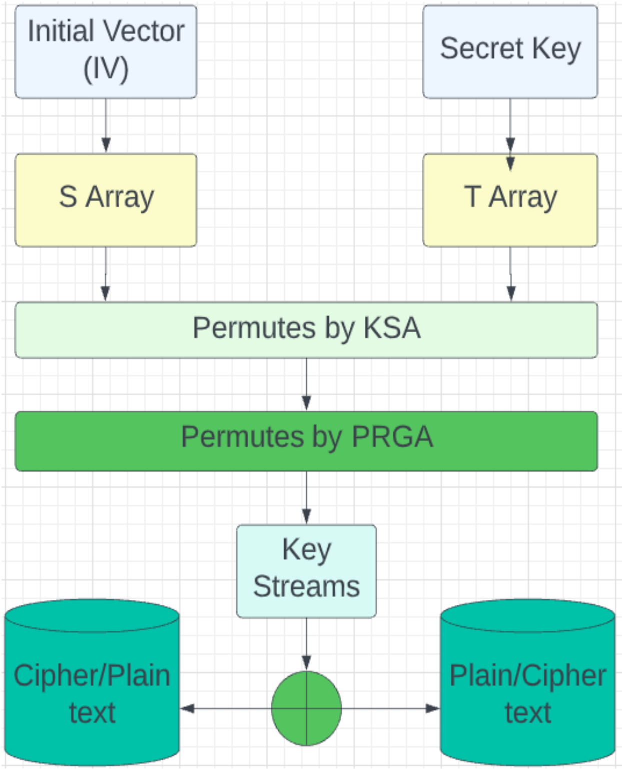


Figure 7 - Overview of RC4 Algorithm [9]

2) TCP Protocol

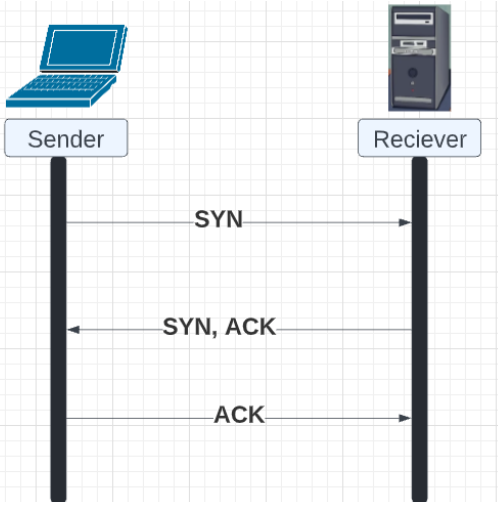


Figure 8- TCP Schema

TCP (Transmission Control Protocol) is a point-to-point connection-oriented transport protocol that sends data packets as an unstructured stream of bytes in an ordered sequence. TCP guarantees data reliability, end-to-end delivery, resequencing, and retransmission until a timeout condition is met or data packets are acknowledged. Loss of packets triggers a retransmission process to retrieve the packet.

3) UDP Protocol

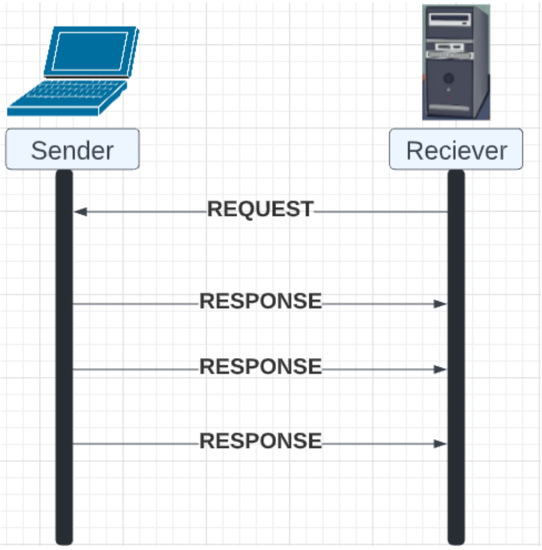


Figure 9- UDP Schema

UDP (User Datagram Protocol) is a connectionless transport layer communication protocol for establishing low tolerance and loss latency connections for the delivery of services or packets within or across networks. As an alternative to the TCP/IP protocol, it is combined with an internet protocol suite. Loss of packets do not force any retransmissions.

4) Error Expectancy: TCP vs UDP

As TCP is a reliable protocol, error expectancy is expected to be almost zero due to retransmission of lost or corrupted packets. While UDP is a connectionless protocol, it is not concerned about data loss. As a result, error expectancy for the UDP protocol might vary from packet to packet and is obtained to be higher than the TCP protocol.

5) Error Probability for the System

TCP has a zero-percentage error probability when used with any encryption. The error probability for UDP varies depending on the block or stream ciphers used. In the case of stream ciphers, individual bits are affected, whereas any faults during data transfer across the network affect the entire block for the case of block cipher. Affected individual bits may cause slight or unnoticeable errors in the outputted image compared to the block cipher where the loss or unordering of a packet can cause a noticeable error to the outputted image.

Therefore, in UDP, Stream cipher's fault tolerance aids in localizing mistakes and producing a clear image than block cipher with the same percentage errors.

Performance (Stream Cipher) >

Performance (Block Cipher)

Performance comparison based on the face that

Error tolerance (Stream Cipher) >

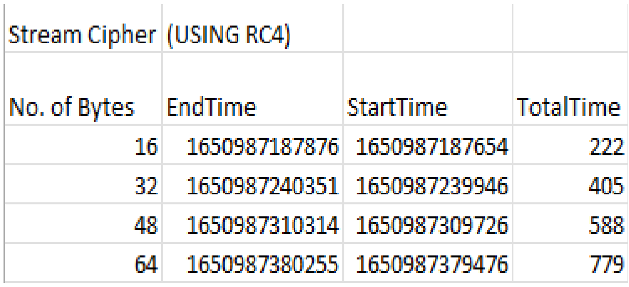
Error tolerance (Block Cipher)

6) Performance comparison of Block cipher vs Stream cipher on TCP and UDP

TCP is a reliable protocol. Hence, there is no loss of packets during the transmission. If such a case happens, TCP will try to retransmit the packet. Hence, there won't be a difference in the output for block cipher or stream cipher. While in the case of UDP, there is no retransmission and some packets being lost is of no concern to UDP. TCP takes more time as compared to UDP to retransmit some lost packets even then this maybe of small difference. Even though the image or information is delivered perfectly by TCP, it still takes additional time to deliver the packets as compared to UDP. Block cipher can have corrupted blocks and hence greater error in the outputted image. While stream ciphers are more resistant due to loss of few bits here and there. Thus, stream ciphers have better performance although block ciphers are more secure.

Elementary Results [Code Attached]:

i) Time Taken for transmission of Stream Cipher over TCP

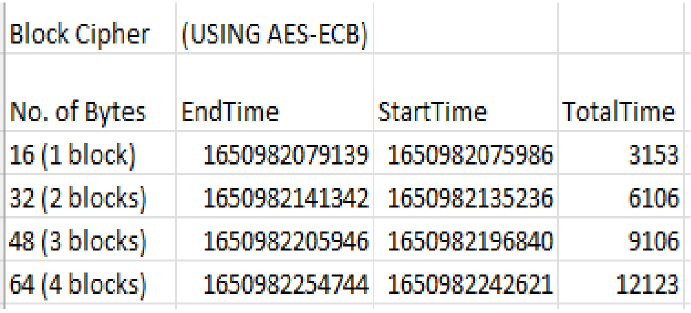


Stream Cipher	(USING RC4)		
No. of Bytes	EndTime	StartTime	TotalTime
16	1650987187876	1650987187654	222
32	1650987240351	1650987239946	405
48	1650987310314	1650987309726	588
64	1650987380255	1650987379476	779

Figure 10- Time Taken- Stream Cipher - TCP

Total Time Taken is in milliseconds

ii) Time taken for transmission of Block Cipher over TCP

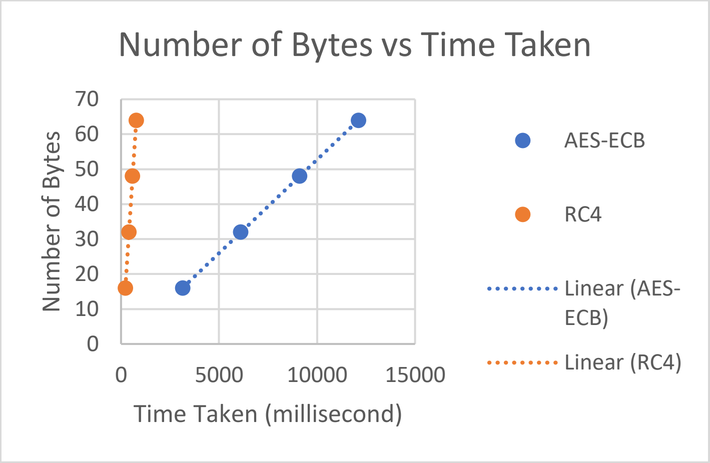


Block Cipher	(USING AES-ECB)		
No. of Bytes	EndTime	StartTime	TotalTime
16 (1 block)	1650982079139	1650982075986	3153
32 (2 blocks)	1650982141342	1650982135236	6106
48 (3 blocks)	1650982205946	1650982196840	9106
64 (4 blocks)	1650982254744	1650982242621	12123

Figure 11- Time Taken - Block Cipher - TCP

Total Time Taken is in milliseconds

Graph Comparison between Time taken for transmission over TCP (AES-ECB vs RC4)

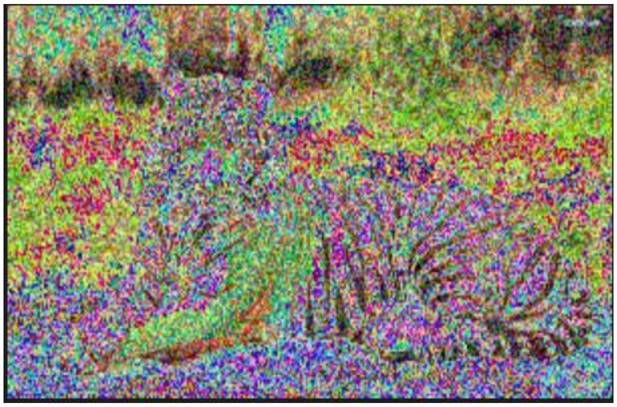


As shown in the graph, RC4 is significantly faster than AES-ECB if only one of the specified number of bytes is corrupted or unordered. If any bytes are determined to be corrupted or missing, the entire block must be retransmitted. Due to this nature of block ciphers, Stream ciphers are thus much faster but less secure than block ciphers.

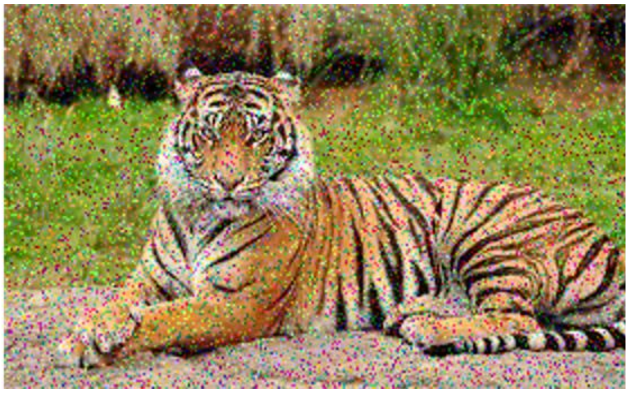
iii) Stream Cipher with UDP

RC4 Algorithm used

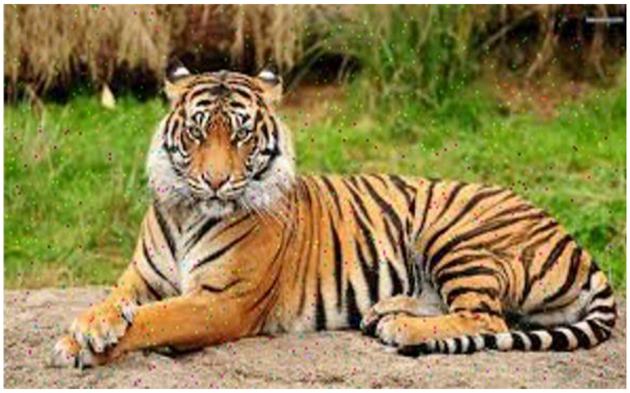
For Threshold = 0.5



For Threshold = 0.1



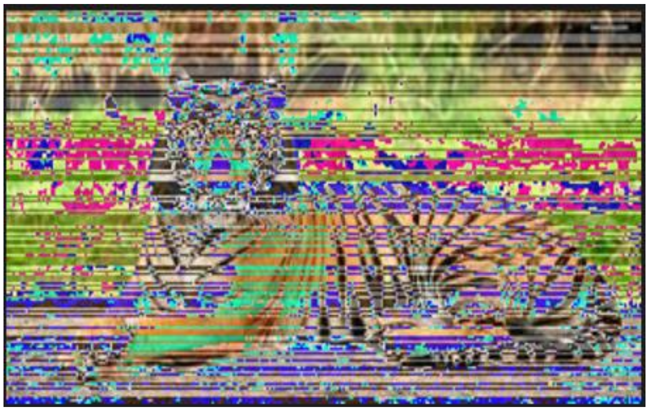
For Threshold = 0.01



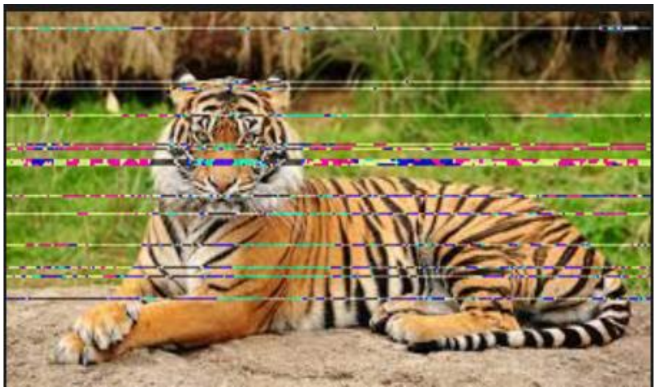
iv) Block Cipher with UDP

AES-CBC Algorithm used

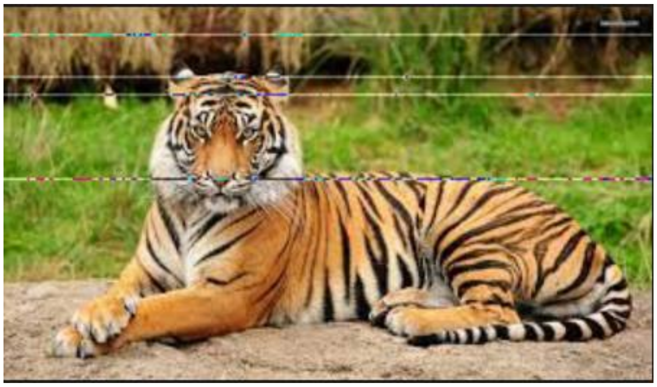
For Threshold = 0.5



For Threshold = 0.1



For Threshold = 0.01



Conclusion:

To summarize, each cryptographic algorithm provides security in some way. The algorithm to be utilized is determined by the application's requirements. The results will reveal that RC4 is unquestionably more effective than AES-CBC in terms of performance and error bit localization. It is also worth noting that AES is more secure than RC4, thus can be fulfil security requirements of some applications.

As observed, UDP with stream ciphers produces very less error, hence, does not affect the overall view of image.

While TCP with stream cipher produces a replica of the received image since there is no loss of packets but takes additional time to deliver packets that are lost and is retransmitted. Implementation figures suggest that Stream ciphers using RC4 algorithm over TCP takes some milliseconds less than Block ciphers that was using AES-ECB algorithm for the same number of Bytes or block size.

Using java, we checked the transmission of UDP protocol without any error percentages [Hence acting as a TCP Protocol]. Thus, we obtain a clear image from the transmitter to the receiver.

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