A Virtual-Internetworking-Stack (VIS) Approach to Achieve a Flexible, Proprietary Security Model by Augmentation of the Transport Layer under the Collaborative Framework of Sine Wave Encryption Technique and Generation of Color QR Codes

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Abstract

Due to potentially peer works going on to address the loopholes in the existing system research works in Internet Security is never likely to saturate. The degree of one's need of security on Internet varies with one's economical, organizational and political position and the sensitivity of the information itself. This thesis envisages a Virtual Internetworking Stack (VIS), achieved by augmentation of the TCP/IP stack to befool possible cyber vigilance on one's activities over the Internet. The model prescribes a secure session set-up randomly by exchanging colored QR codes, where the wavelength of the color determines the phase of a sinusoid used to encrypt/decrypt a message, which is understood only by a compatible and intended VIS-stack. Since, the augmentation of TCP/IP layer is done in the Kernel of the user's Operating System, any message that this VIS-stack sends to another VIS-stack across the Internet, will be meaningless to the routers and gateways in between which participate in cyber vigilance; and an attempt to steal one's information will be fooled by the proposed security model. We also present a vulnerability study and performance evaluation of the augmented TCP/IP stack, obtained by results of physically performed experiments.

Keywords: *Augmentation of TCP/IP stack, Color QR codes, Sine Wave Encryption, Proprietary Security model*

1. Introduction

Internet is a vast ocean of communication and majority of the world population prefer to communicate over Internet. Like everything else in a communication system, there is need to secure information travelling across different nodes (Routers) of this ocean. The degree of need to secure one's communication depends on one's economical, organizational and political position. For example, a banking portal will demand much more security than a social friendship portal. An e-commerce portal must have better security than a portal that hosts technical discussion forums. Also, we must admit that the email account of a business tycoon or the President of a country will demand more security than a commonplace civilian's. And while it comes to secure a piece of information that relates to the defense of a country, the extreme security is expected, together with the biggest threat of getting it leaked. In certain cases, the trust on one's ISP, too, varies. The defense personnel of a nation must not be as much casual to exchange information with colleagues, as common civilian can be; they

must not, for example, use public or unauthorized Internet connections for communication. Beyond a certain constraint, one defense personnel may not trust even his fellow comrade, being apprehensive of sabotage. Sometimes, rivalries among big organizations do not allow an employee to communicate certain trade secrets, a patent document for example, using an unauthorized Internet connection. This thesis proposes a security model to incorporate any standard or proprietary Cryptography technique to secure a communication by dint of augmenting the Transport layer of the TCP/IP stack of the user's Operating System. This security model is based on establishing a secure connection by exchanging encrypted bytes of colored QR codes, which carry different parameters to compute the encryption/ decryption key(s). This technique is unique in that, a sine wave is used to encrypt data such that the phase of the wave depends on the timestamp of the message, and that the color of QR codes represents its wave length. The augmentation of transport layer takes care that the key depends on a function of the transport layer (TCP) header. Comprising of all these constraints, the security model envisioned here, allows highly secure communications to take place over a public or unauthorized Internet connection with high assurance of privacy. This is because of the transport layer augmentation which is understood only by the Operating Systems of the communicating machines. The rest of the world is rendered unaware of the data. At the same time, keeping the Network layer intact ensures that the routers, through which the network layer packets must pass across the World Wide Web, will not treat the packets corrupt and hence drop them. So, achieving invincible security system while one uses a public and unauthorized network is the outcome of the thesis. The author carried out successive experiments to test vulnerability and performance (scalability) of the Security model, and presents in this research paper, the results and analysis together with the description of the entire process of augmenting the Transport layer.

2. Proposed Model

The security model envisaged in this thesis is achieved by augmentation of the transport layer and introducing just above it an abstract security layer. Throughout the thesis the augmented TCP/IP stack will be referred to as the Virtual Internetworking Stack (VIS) and the introduced security layer as the Opaque Security Layer (OSL). The VIS is shown in Figure 1. The security layer is abstract and opaque because implementation of this very layer is not suggested by the thesis and it does not recommend it to adhere to any standardization. Rather, implementation of this intermediary layer is supposed to use proprietary security algorithms to keep the security architecture as little exposed to the outsider bodies. For example, an application developer, who may be consulted by an organization to develop an secure Network application requiring the augmented stack (VIS), must not require any information about the underlying security mechanisms and nor even the VIS itself. As will appear to a third party software vendor, it is simply a Network application operating in the Application Layer. This will make this security model more flexible to use without compromising the VIS architecture or its implementation to a third party software vendor. The functionality of the VIS involves two major things:

Figure 1. The Schematic Diagram Vis

- A shared knowledgebase that is had with the VIS
- A 4-way secure session set up process between two communication partners. The partner which requests for a secure session is referred to as a Client and who it requests is referred to as a Server. The OSL defines 5 different packet formats as shown in Figure 7. The first four types of packets are used during the process of setting up a secure session, while the last type of packets is a data packet, which is exchanged after a secure session has already been established between the Server and the Client. Section 2.2 presents a detailed discussion on the anatomy of these 5 OSL packets.

2.1 Shared Knowledgebase

The shared knowledgebase within the *VIS* is logically divided to belong to two layers: The *OSL* layer the *augmented Transport Layer*. Table 1 shows and explain the implications of the shared knowledgebase in a *VIS* distributed between the *augmented* transport layer and the *OSL*.

Table 1. Shared Knowledgebase of the Augmented Transport Layer

Serial	Entity Name	Description
1	$g(\text{byte[]} a)$	A function that operates on TCP header bytes. The parameter a represents the byte array
2	$f(\text{long } t_s)$	A function of timestamp of the packet. The parameter represents the timestamp (8 bytes)
3	$p(\text{double } q)$	A function operating on the wavelength of a color light. The parameter represents the wave length
4	$E(X, K)$	A symmetric cryptography algorithm encrypting (or decrypting) X with the $\text{key}=K$
5	Color-Wavelength map	This is a hash map of a color and the wave length of light wave of that color. This is shown in Sec. [1.a]

Table 1a. COLOR HASH MAP

Color	Frequency	Wavelength	Average Wavelength
Violet	668–789 THz	380–450 nm	400 nm
Blue	606–668 THz	450–495 nm	470 nm
Green	526–606 THz	495–570 nm	550 nm
Yellow	508–526 THz	570–590 nm	580 nm
Orange	484–508 THz	590–620 nm	600 nm
Red	400–484 THz	620–750 nm	700 nm

2.2. Anatomy of the OSL Packets

The five *OSL* packets have the first two fields in common, the *Packet Type* (1 byte) and the *Timestamp* (8 bytes). Since there are 5 packet definitions to the *OSL*, they are assigned five initial identification numbers: 0, 1, 2, 3, 4. However, to strictly identify an incoming packet as belonging to any of these 5 packets, bits of the first field, i.e., the field *Packet Type* (1 byte) is subdivided; the first 3 bits represent the raw-numbers (i.e., 0, 1, 2, 3, 4) assigned to an *OSL* packet. The first 3 bits accommodate the binary equivalents of the numbers {0, 1, 2, 3, 4}, i.e., $(000)_2$, $(001)_2$, $(010)_2$, $(011)_2$, $(100)_2$ respectively, in binary number system.

The remaining $(8-3) = 5$ bits are made to contain the value obtained by performing modulo operation on the timestamp by 32. Because, $(2^5 - 1) = 31$ is the maximum of the unsigned integers we can form with these remaining 5 bits. So, remainder of a positive number (like the timestamp, which is 8 bytes long) by 32 ensures that remainder will never exceed 31.

Value of the field *Packet Type* of a packet, formed at a timestamp = T_s is, therefore, $\{x\ y\ z\ b_4\ b_3\ b_2\ b_1\ b_0\}$ expressed in binary, where $b_4\ b_3\ b_2\ b_1\ b_0$ is the binary representation of $(T_s \bmod 32)$; whereas $\{x\ y\ z\}_2$ represent the raw number assigned to the packet type. So, for the first packet type these three bits are 000 to represent the type = 0. The calculation of the value of the first byte of an *OSL* Packet is discussed in *Algorithm 1* Table 2 which also takes a look at the anatomy of all these five packets.

Among the 5 *OSL* packets, the first one is referred to as the **SESSION REQUEST** packet. It has 3 fields: **Packet Type** (1 byte), **Timestamp** (8 bytes) and **Request-DATA** field (variable). The first 3 bits of this packet are {000}.

Value of the field *Packet Type* of a SESSION REQUEST Packet formed at a timestamp, 13835440 80111, is therefore = $(15)_{10}$. This can be calculated as below:

Table 2. Anatomy of the OSL Packets

Algorithm 1: Generic Calculation of the value of the field Packet-Type for all 5 OSL Packets	
1	<p>The raw value of the packet type is expressed in 3-bit binary and are accommodated in 3 <i>Most Significant Bits</i> of the field Packet-Type.</p> <p>Examples:</p> <ol style="list-style-type: none"> The raw value assigned to a SESSION REQUEST packet is 0. So the most significant 3 bits in this field contain {000}. The raw value assigned to a CHALLENGE PACKET is 1. So the 3 most significant bits in this field of this very type of OSL packets contain {001}. The raw value assigned to a RESPONSE PACKET is 2. So the 3 most significant bits in this field of this type of OSL packets contain {010}. The raw value assigned to an F is 3. So the 3 most significant bits in this field of this type of OSL packets contain {011}. The raw value assigned to a DATA COMMUNICATION PACKET is 4. So the 3 most significant bits in this field of this very type of OSL packets contain {100}.
2	<p>Let T_s be the timestamp when an OSL packet was formed.</p> <p>We obtain the remainder R by division of T_s with the divisor 32. Thus, $R = T_s \bmod 32$</p> <p>This is expressed in binary and since $R < 32$, it can be accommodated in the remaining 5 bits of the 8-bit field.</p>
3	<p>Now the <i>final</i> value of the 8-bit field is calculated.</p> <p>Examples: (Assuming the $T_s = 13835440\ 80,111$)</p> <p>$R = 15$ i.e. $(01111)_2$</p> <ol style="list-style-type: none"> For the SESSION REQUEST packet this value is $\{\underline{000}\ 01111\}_2 = 15$ For the CHALLENGE PACKET this value is $\{\underline{001}\ 01111\}_2 = 47$ For the RESPONSE PACKET this value is $\{\underline{010}\ 01111\}_2 = 79$ For the OSL-ACKNOWLEDGMENT PACKET this value is $\{\underline{011}\ 01111\}_2 = 111$ For the Data Communication packet this value is $\{\underline{100}\ 01111\}_2 = 143 = -113$ (overflowed to fit in 8 bit signed integer arithmetic) <p>Note: The 3 most significant bits which accommodate the raw numbers, are underlined</p>

In a **CHALLENGE PACKET** the Size of the field **QR-DATA** = the Value of the field **QR-LEN**

In DATA COMMUNICATION PACKET, the size of the **DATA** field= the value of the field **D_LEN**

Initially the *Client* sends this packet asking the *Server* to set up and open a secure *opaque* session. The *Server* sends a challenge packet, the second of the 5 *OSL* packets, to the *Client*. This packet, referred to as the **CHALLENGE PACKET**, consists of five fields, Packet Type (1 byte), Timestamp (8 bytes) *QR-LEN* (2 bytes) , *QR-DATA* (variable) and *SIGNATURE-ALIAS* (variable) . The value of Packet Type field is calculated is above, treating the packet type to be $(1)_{10}$ i.e., $(001)_2$.

The *third* packet is a *RESPONSE* packet, containing four fields, Packet Type (1 byte), Timestamp (8 bytes), *RESPONSE* (4 bytes) and *SIGNATURE-ALIAS* (variable). The first two fields, *packet type* and *timestamp* have same implication as in the previous two packets; and the first 3 bits of first field, i.e., *Packet Type*, accommodate the value $(2)_{10} = (010)_2$.

The *fourth* of these *OSL* packets is an acknowledgement that the *Server* sends to the *Client* acknowledging that a secure *opaque* session has been set up and how long it will be valid. The fields of this acknowledgement packet are *Packet Type* (1 byte), *Timestamp* (8 bytes),

Session ID (4 bytes), *SESSION EXPIRES AFETR* (4 bytes), and a *SIGNATURE ALIAS* (variable). The first three bits of the field *Packet Type* accommodate the decimal number 3, i.e., $(101)_2$. This is referred to as the **OSL Acknowledgement Packet**.

The last of the *OSL* packet types is a *Data Communication* packet, which the communicating partners i.e., the *Client* and the *Server* exchange between themselves after an opaque, secure session has been established. This packet consists of the following five fields: *Packet Type* (1 byte), *Timestamp* (8 bytes), *D_LEN* (2 bytes), *DATA* (variable) and the *SIGNATURE ALIAS* (variable). The first 3 bits of the first field, i.e., *Packet Type* accommodate the decimal number 4, represented as $(100)_2$.

2.3. Secure Session Establishment

As overviewed in Section 2.2, the process of establishing an *OSL* session between two communicating partners is shown in the timeline-diagram presented in Figure 2. The session is set up following successful completion of 4 phases of packet exchange.

2.3.1. Session Request: The *Client* requests the *Server* to set up an *OSL* session by sending a **SESSION REQUEST** Packet. This process of generating a request at the *Client* stack (*VIS*) is described in *Algorithm 2* Table 3. The request is received and understood by the *Server* to be a request at the transport layer. The layers below, however, cannot have a clue of this. The transport layer is such *augmented* that in a receiving stack (*VIS*), it will deliver any of the five *OSL* packets to the *OSL* layer, instead of forwarding it directly to the Application layer. The processing logic of a **SESSION REQUEST** packet is described in Table 4. The table also illustrates how the *VIS* of the *Server* creates a **CHALLENGE PACKET** for the *Client*.

Table 3. Formation of Session Request Packet

ALGORITHM 2: FORMATION OF SESSION REQUEST PACKET		
O S L	1	The OSL of the <i>Client VIS</i> picks the current timestamp (t_0) of system, and calculates a value K with its knowledgebase function $f(t)$. Outcome of this step: $K=f(t_0)$
	2	Each <i>VIS</i> has authentication parameters (user id and password) which identify the user of the computer within an Organization. Let us assume that the <i>Client VIS</i> has U and P as the user id and the password. The OSL encrypts these two parameters using a common symmetric cryptography algorithm E and using K as the key. A String S is obtained from U' and P' using [Algorithm 3.1] described in [Table-10] Outcome of this step: $U' := E(U, K)$ and $P' := E(P, K)$ $S := \Sigma(U', P')$, here the operator Σ represents string generation operation Algorithm 3.1 [Table-10]
L	3	A color is picked up at random from the Color-Frequency Hash Map shown in Table 1

A Y E R	4	<p>The OSL forms a color QR code with S. The color of the QR code is same as the color chosen in the previous step</p> <p>Outcome of this step: $qrCode := QR(S, color)$, where $QR(A,C)$ is the operation of making a QR code of color C with a Text A $Q[] := bytesOf(qrCode)$, where $bytesOf(qrCode)$ represents the operation of extracting raw bytes from the QR code $qrCode$</p>							
	5	<p>The OSL now creates a SESSION REQUEST packet such that</p> <table><tr><td>a.</td><td>The first field contains the packet type in <i>one</i> byte, as per Algorithm 1 in [Table-2]</td></tr><tr><td>b.</td><td>The next field, i.e. next 8 bytes contain the timestamp t_0</td></tr><tr><td>c.</td><td>The next bytes accommodate the byte array Q[]</td></tr></table>	a.	The first field contains the packet type in <i>one</i> byte, as per Algorithm 1 in [Table-2]	b.	The next field, i.e. next 8 bytes contain the timestamp t_0	c.	The next bytes accommodate the byte array Q[]	
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	b.	The next field, i.e. next 8 bytes contain the timestamp t_0							
c.	The next bytes accommodate the byte array Q[]								
6	<p>The OSL level formation of the SESSION REQUEST packet is complete and it travels down the VIS to the augmented transport layer.</p>								
T R A N S P O R T L A Y E R	7	<p>The Transport layer of the VIS is augmented in such a way that any packet that comes down the Network stack directly from the OSL must be processed by the augmentation logic. The SESSION REQUEST packet is modified by the Transport layer augmentation logic as follows:</p> <table><tr><td>i)</td><td>The transport layer calculates a value h, which is a digest of the TCP header Outcome of this step: $h=g(\text{current TCP header})$</td></tr><tr><td>ii)</td><td>The data part of TCP packet, i.e. the OSL-level SESSION REQUEST packet is modified such that the last field (i.e. 10^{th} byte onwards) is encrypted using the symmetric cryptography algorithm E with the key h Outcome of this step: FOR $I=0$ TO $(Q.length-1)$ $PACKET_DATA[I+9]= E(PACKET_DATA[I+9], h)$ NEXT I</td></tr></table>	i)	The transport layer calculates a value h , which is a digest of the TCP header Outcome of this step: $h=g(\text{current TCP header})$	ii)	The data part of TCP packet, i.e. the OSL -level SESSION REQUEST packet is modified such that the last field (i.e. 10^{th} byte onwards) is encrypted using the symmetric cryptography algorithm E with the key h Outcome of this step: FOR $I=0$ TO $(Q.length-1)$ $PACKET_DATA[I+9]= E(PACKET_DATA[I+9], h)$ NEXT I			
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Figure 2. Timeline Diagram of Secure Set-up

The Packets Defined by the OSL Layer

Packet Name	Raw PacketType	Function
SESSION REQUEST	0x00	From client to server asking to set up connection
OSL CHALLENGE	0x01	From server to client on successful verification of client's PAP credentials
OSL RESPONSE	0x02	From client to server responding to the challenge
OSL ACKNOWLEDGEMENT	0x03	From server to client acking successful connection set-up
DATA COMMUNICATION	0x04	Message in any direction after connection was setup

Figure 7. Packets Defined by the VIS

Table 4. Algorithm 3

ALGORITHM 3: PROCESSING OF SESSION REQUEST PACKET AND FORMATION OF THE CHALLENGE PACKET AT THE SERVER (RECEIVER) VIS		
TRANSPORT	1	<p>It performs a check according to <i>Algorithm 12</i> described in [Table-11] to check if this is an <i>OSL</i> packet.</p> <p>Outcome of this step:</p> <p>IF (the packet is found to be an <i>OSL</i> packet) Then</p> <p style="text-align: right;">IF (the packet is <i>SESSION REQUEST</i> packet) Then</p> <p style="text-align: right;"><i>Execute steps STEP-2 onwards</i></p> <p style="text-align: right;">ELSE</p> <p style="text-align: right;"><i>Use (other) packet specific Algorithms</i></p> <p style="text-align: right;">END-IF</p> <p>ELSE</p> <p style="text-align: right;"><i>Forward the packet to the application layer</i></p> <p>END-IF</p>
	2	De-encapsulate the TCP header and payload separately
	3	<p>The transport layer calculates the digest of the TCP packet's headers.</p> <p>Outcome of this step: $h = g(H[I])$</p>
	4	<p>Using h as the key, perform the symmetric decryption on the payload starting with the 10^{th} byte onwards.</p> <p>For $I=9$ to $\text{length}(D[I])$</p> <p style="text-align: center;">$D[I] := E(D[I], h)$</p> <p>Next I</p> <p>Outcome of this step:</p> <p style="margin-left: 40px;">a) The QR bytes of the <i>SESSION REQUEST</i> packet</p> <p style="margin-left: 40px;">b) The payload with the bytes of the <i>REQUEST</i> field described, are forwarded to the <i>OSL</i></p>
O	5	<p>The bytes of the packet are parsed and the fields are separated out.</p> <p>Outcome of this step:</p> <p style="margin-left: 40px;">a) The timestamp of the packet (t_0)</p> <p style="margin-left: 40px;">b) The QR bytes which involves the request parameters</p>
	6	Computes $K = f(t_0)$
	7	The QR code is formed with the last of the three fields of the <i>SESSION REQUEST</i> packet.

S L L A Y E R		Outcome of this step: the <i>QR</i> code
	8	From QR code the text (<i>S</i>) is extracted. Also, the color of the QR code is found out. Outcome of this step: a) $S := QR^{-1}(qrCode)$ b) $color := colorOf(qrCode)$ c) $\lambda = wavelength(color)$
	9	The QR text obtained in the previous step is parsed to yield the encrypted user id and password Outcome of this step: a) <i>U</i> b) <i>P</i>
	10	With <i>K</i> as the key, the symmetric decryption, <i>E</i> is carried out to find the user id and password: $U := E(U, K)$ $P := E(P, K)$ Outcome of this step: <i>U</i> and <i>P</i> (User authentication parameters)
	11	The user id and password are looked up for a match in a user database. The authentication is carried out using a local or remote database. IF authentication fails Then o Block connection o Take an action to prevent farther attacks [This step is Optional and is directly NOT a part of the envisaged security mode] ELSE <i>Perform steps 12 onwards</i> END-IF
	12	Fetch the Public Key of the user (authenticated in step-11) from a database maintained under PKI
	13	Generate two random numbers. Outcome of this step: a) $A := Rnd()$ b) $X := Rnd()$
	14	Compute the p-Function of the wavelength of the color found out in STEP-8c Outcome of this step: $W = p(\lambda)$
	15	The two numbers are symmetrically encrypted using the key, <i>W</i> Outcome of this step: a) $A' := E(A, W)$ b) $X := E(X, W)$
	16	Create a random integer to be used as the <i>Challenge</i> . Outcome of this step: $C := Rnd()$
	17	Fetch self-timestamp (timestamp of itself). Outcome of this step: $t_1 := \text{Self-timestamp}$

	18	Compute a number K_1 such that $K_1 := f(t_1)$
	19	Encrypt the challenge symmetrically with the key, K_1 Outcome of this step: $C' := E(C, K_1)$
	20	Create a String S with A' , X' and C' using some logic exemplified in [Algorithm 3.1] in [Table-10] Outcome of this step: S
	21	Create a QR code with the string, S and get its raw bytes in an array of bytes, Q Outcome of this step: a) $qrCode := QR(S)$, b) $Q[] := bytesOf(qrCode)$
	22	Compute another random number, R . Outcome of this step: $R := Rnd()$
	23	Encrypt the raw bytes of the QR code image symmetrically with R . FOR $I=0$ to $length(Q)$ $Q[I] := E(Q[I], R)$ NEXT I
	24	Encrypt R asymmetrically with the public key of the Client fetched in [STEP -12] Outcome of this step: $R := E_{+ Client}(R)$
Transport Layer	25	The <i>Opaque Security Layer</i> creates a CHALLENGE packet which consists of the following fields, whose values and length in bytes are given below... a) Packet Type: (1 byte) calculated according to Algorithm 1 [TABLE-2] b) Timestamp : t_1 (8 bytes) c) QR-Len: $length(Q)$ (4 bytes) d) QR-data: Q (variable) e) Signature-alias: R (variable; depends on public key of the client)
	26	This packet travels downwards to the Transport layer, and is encapsulated within a TCP packet [Figure-3]
	27	The packet comes down the <i>VIS</i> and is finally sent at <i>Layer-0</i> of the Network Stack

2.3.2 Processing of the Challenge Packet at the Client VIS: When the *Client* receives the challenge from the server, the Transport layer of the *VIS* recognizes it to be a challenge packet. The Transport layer de-encapsulates and processes it before forwarding it to the upper layer, i.e., the *OSL*. The *OSL* layer processes the augmented transport layer packet and creates a response to challenge. The processing the **CHALLENGE PACKET** is described in Algorithm 4 Table 5.

Table 5. Algorithm 4

ALGORITHM 4: PROCESSING OF THE CHALLENGE PACKET AT THE CLIENT'S VIS		
T R A N S P O R T L A Y E R	1	<p>The Transport layer performs a check according to <i>Algorithm 11</i> described in [Table-11] to check if this is an <i>OSL</i> packet.</p> <p>Outcome of this step:</p> <p>IF (the packet is found to be an <i>OSL</i> packet) Then</p> <p style="padding-left: 40px;">IF (the packet is <i>CHALLENGE PACKET</i>) Then</p> <p style="padding-left: 80px;">Forward to <i>OSL</i> layer</p> <p style="padding-left: 80px;">Execute from <i>STEP-2</i> onwards</p> <p style="padding-left: 40px;">ELSE</p> <p style="padding-left: 80px;">Use (other) packet specific Algorithms</p> <p style="padding-left: 80px;">Forward to <i>OSL</i> layer</p> <p style="padding-left: 40px;">END-IF</p> <p>ELSE</p> <p style="padding-left: 40px;">Forward the packet to the application layer</p> <p>END-IF</p>
	2	<p>The <i>OSL</i> extracts the values of the different fields of the <i>CHALLENGE PACKET</i></p> <p>Outcome of this step:</p> <p>a) Packet Type: (byte No=0)</p> <p>b) Timestamp : t_1 (Next 8 bytes i.e. Bytes 1 to 8)</p> <p>c) QR-Len: $length(Q)$ (Next 4 bytes, i.e. Bytes 9 to 12)</p> <p>d) QR-data: QD (Next <i>QR-LEN</i> bytes)</p> <p>e) Signature-alias: R (Remaining Bytes)</p>
	3	<p>Decrypt the signature-alias with its own Private Key.</p> <p>Outcome of this step: $R := E_{Client}(R)$</p>
	4	<p>Decrypt the raw bytes of the field, <i>QR-data</i> symmetrically with the key, R.</p> <p>Outcome of this step:</p> <p>For $I=0$ TO $LENGTH(QD)$</p> <p style="padding-left: 40px;">$QD[I] := E(QD[I], R)$</p> <p>Next I</p>
	5	<p>Form a QR code with the decrypted bytes</p> <p>Outcome of this step: $Q := QR(QD)$</p>
	6	<p>Decoding takes place to extract the text from the QR code.</p> <p>Outcome of this step: $qrString := QR^{-1}(Q)$</p>
	7	<p>The text extracted in the previous step is parsed as shown in <i>Algorithm 3.2</i> [Table-10]</p> <p>Outcome of this step: The values, A', X', C'</p>
	8	<p>Calculate the value K_1 such that $K_1 := f(t_1)$</p> <p>Outcome of this step: $K_1 := f(t_1)$</p>
	9	<p>The challenge is decrypted using the symmetric key, K_1</p> <p>Outcome of this step: $C := E(C', K_1)$</p>
	10	<p>Calculate the p-function of the wavelength of the color it (<i>Client VIS</i>) had chosen randomly while creating the <i>SESSION REQUEST</i> packet, as shown in <i>Step-3 of Algorithm-2</i> [Table-3]</p> <p>Outcome of this step: $W := p(\lambda)$</p>
O S L	10	<p>A' and X' are decrypted using the symmetric key, W</p> <p>Outcome of this step: $A := E(A', W)$ $X := E(X', W)$</p>
	11	<p>Now the <i>RESPONSE PACKET</i> is created in <i>OSL</i> layer as described in [Algorithm 5]</p>

Table 5.1. Algorithm 5

ALGORITHM 5: CREATION OF THE RESPONSE PACKET																	
OSL Layer	1	Calculate the current timestamp of the system Outcome of this step: $t_2 = \text{current timestamp in milliseconds}$															
	2	Calculate the value(k_2) of the timestamp function such that $k_2 := f(t_2)$															
	3	The values A , X obtained in Step-10 of Algorithm 4 are used in the equation of a sine wave expressed as, $y(t, x) = A \sin \frac{2\pi}{\lambda} (c * t - x)$ where $t = k_2$ and $x = X$ Outcome of this step: $y_2 := A \sin \frac{2\pi}{\lambda} (c * f(t_2) - X)$, where $c = 3 \times 10^8 / 10^8$ [the velocity of light in vacuum space expressed in $m\text{-sec}^{-1} / 10^8$]															
	4	A random number, R_2 is generated Outcome of this step: $R_2 := \text{rnd}()$															
	5	A one-time key K_2 , is computed to be the XOR of y_2 and R_2 Outcome of this step: $K_2 := y_2 \Phi R_2$															
	6	The challenge, <i>i.e.</i> C is encrypted symmetrically with the one-time key, K_2 , to form the response Outcome of this step: $C_{\text{Cipher}} := E(C, K_2)$															
	7	R_2 is encrypted asymmetrically with the private key of the Client. Outcome of this step: $R_2 := E_{\text{Client}}(R_2)$															
	8	The Response packet is created as below and forwarded to the transport layer.															
<table border="1"> <thead> <tr> <th>Field Name</th><th>Field Size in Bytes</th><th>Value of the Field</th></tr> </thead> <tbody> <tr> <td>Packet Type</td><td>1</td><td>calculated according to Algorithm 1 [TABLE-2]</td></tr> <tr> <td>Timestamp</td><td>8</td><td>t_2</td></tr> <tr> <td>Response</td><td>4</td><td>C_{Cipher}</td></tr> <tr> <td>Signature-Alias</td><td>Variable</td><td>R_2</td></tr> </tbody> </table>			Field Name	Field Size in Bytes	Value of the Field	Packet Type	1	calculated according to Algorithm 1 [TABLE-2]	Timestamp	8	t_2	Response	4	C_{Cipher}	Signature-Alias	Variable	R_2
Field Name	Field Size in Bytes	Value of the Field															
Packet Type	1	calculated according to Algorithm 1 [TABLE-2]															
Timestamp	8	t_2															
Response	4	C_{Cipher}															
Signature-Alias	Variable	R_2															
Transport Layer	1	Transport Layer forwards it to the Network Layer down the <i>VIS</i>															

After processing the challenge, the client *VIS* responds to the challenge. The formation of the **RESPONSE PACKET** is illustrated in *Algorithm 5* Table-5.1

2.3.3 Verifying the Response at the Server *VIS*: After the *Server* receives the response, it is recognized to be a **RESPONSE PACKET** at the Transport Layer of the *VIS*. The response is verified by the *OSL* layer as per *Algorithm 6* Table 6. On successful verification of the response, the *Server* sends an Acknowledgement packet which contains the session id and session validity. The process of generating an acknowledgment is described in *Algorithm 7* Table 7

Table 6. Algorithm 6

ALGORITHM 6: PROCESSING OF THE <i>RESPONSE PACKET</i> THE SERVER V/S		
T R A N S P O R T L A Y E R	1	<p>The Transport Layer performs a check according to <i>Algorithm 11</i> described in [Table-11] to check if this is an <i>OSL</i> packet.</p> <p>Outcome of this step:</p> <p>IF (<i>the packet is found to be an OSL packet</i>) Then</p> <p style="padding-left: 40px;">IF (<i>the packet is RESPONSE PACKET</i>) Then</p> <p style="padding-left: 80px;">Forward to <i>OSL</i> layer</p> <p style="padding-left: 80px;">Execute <i>STEP-2</i> onwards</p> <p style="padding-left: 40px;">ELSE</p> <p style="padding-left: 80px;">Use (other) packet specific Algorithms</p> <p style="padding-left: 80px;">Forward to <i>OSL</i> layer</p> <p style="padding-left: 40px;">END-IF</p> <p>ELSE</p> <p style="padding-left: 40px;">Forward the packet to the application layer</p> <p>END-IF</p>
	2	<p>The packet is de-encapsulated at the <i>OSL</i> layer. The fields of the payloads are extracted</p> <p>Outcome of this step:</p> <ul style="list-style-type: none"> ▪ The timestamp (t_2) of the packet (2nd Byte to 9th Byte) = 8 bytes ▪ The response (R) (10th Byte to 13th Byte)= 4 Bytes ▪ The Signature Alias(S) (14th Byte onwards)
	3	<p>Compute the value (k_2) of timestamp function</p> <p>Outcome of this step: $k_2 := f(t_2)$</p>
	4	<p>Decrypt the Signature by the public key of the <i>Client</i></p> <p>Outcome of this step: $R_2 := E_{+Client}(S)$</p>
	5	<p>Computes the value of the magnitude (Positive value of the amplitude) of the Sine Wave.</p> <p>Outcome of this step:</p> <p>$y_2 := A \sin \frac{2\pi}{\lambda}(c * f(t) - x)$ where $t = t_2$, & A, λ have already been exchanged in earlier phases</p> <p>$c = 3 = 3 \times 10^8 / 10^8 =$ [the velocity of light in vacuum space expressed in $m\text{-sec}^{-1} / 10^8$]</p>
	6	<p>Computes the one-time key (K_2)</p> <p>$K_2 := R_2 \Phi y_2$</p>
	7	<p>The response, i.e. C is decrypted symmetrically with K_2</p> <p>Outcome of this step: $C_1 := E(R, K_2)$</p>
	8	<p>$C :=$ The challenge generated by the <i>Server OSL</i> in <i>STEP-16 of Algorithm 3</i> [Table-4]</p>

9	IF $C_1 == C$ Then
	a) Accept to communicate with the Client b) Create an OSL <i>ACKNOWLEDGEMENT PACKET</i> and send it to client illustrated in [Algorithm 7] c) Continue communication till client does or session expires, whichever is earlier
	ELSE
	a) Decline the connection b) [Optionally] Take action against Cyber intrusion according to policies of the respective organization.
	END IF

Table 7. Final Step of 4-way Session Establishment Generation of Acknowledgement

ALGORITHM 7: CREATION OF OSL ACKNOWLEDGEMENT PACKET AT THE SERVER V/S				
O S L	1	Generates a unique session ID (S_ID) which the server maintains in a database. [Table-7] shows a sample table schema of a session table.		
	2	$t_3 :=$ Current Timestamp		
	3	Compute the validity of the session in milliseconds Outcome of this step: $VT :=$ validity of the session elapsed since t_3 (In milliseconds)		
	4	Generate a random number. Outcome of this step: $R := \text{rnd}()$		
	5	Computes the magnitude of the sine wave using current timestamp Outcome of this step: $y_3 := A \sin \frac{2\pi}{\lambda} (c * f(t) - x) $ where $t = t_3$		
	6	Compute the p -value of the wavelength Outcome of this step: $w := p(\lambda)$		
	7	Compute the symmetric key for encrypting the session id composited by y_3 and R Outcome of this step: $Z_1 = y_3 \oplus R$		
	8	Compute the symmetric key for encrypting the value of Valid-Till field composited by w and R Outcome of this step: $Z_2 = w \oplus R$		
	9	Encrypt the session id symmetrically with the key, Z_1 Outcome of this step: $S_ID := E(S_ID, Z_1)$		
	10	Encrypt the VT field by Z_2 Outcome of this step: $VT := E(VT, Z_2)$		
	11	Encrypt R with the public key of the <i>Client</i> to form a <i>SIGNATURE ALIAS</i> Outcome of this step: $S := E_{+ \text{Client}}(R)$		
	12	Create the OSL Acknowledgement Packet with the following fields and forwards it to the Transport Layer.		
L A Y E R		Field Name	Field Position	Field Size in Bytes
		<i>Packet Type</i>	1 st Byte	1 Byte
		<i>Timestamp</i>	2 nd Byte - 9 th Byte	8 Bytes
		<i>Session Validity</i>	10 th Byte - 13 th Byte	4 Bytes
		<i>Session ID</i>	14 th Byte - 17 th Byte	4 Bytes
		<i>Signature ALIAS</i>	18 th bytes onwards	VARIABLE
Transport Layer	1	The transport layer forwards it to the network layer down the <i>VIS</i> .		

2.4 Data Communication Post Establishment of a Secure Session

After a secure session has been established between the *Server* and the *Client*, communication can continue until the session expires or they mutually end the session, whichever takes place earlier. The process of encryption of a *DATA PACKET* at the sender-side *VIS* is illustrated in *Algorithm 8* Table 8. *Algorithm 9* Table 9 depicts how a receiver-side *VIS* processes and decrypts a *DATA PACKET*. Both the tables present respective *algorithms* with layer-wise break-up to help us understand how the *augmentation* of the ***Transport layer*** and the ***Opaque Security Layer*** (OSL) collaborate with each other in a *VIS*.

Table 8. Algorithm 8

Algorithm 8: Creation and Encryption Technique of Data Packet at the sender vis		
Application Layer	1	Generate application data bytes $D[]$. The data is forwarded to the <i>OSL</i> layer.
OSL <		

	10	A DATA_COMM packet is formed in the application layer with the following fields			
		Field Name	Field Position	Field Size (in Bytes)	Field Value
		FIELD TYPE	1 st Byte	1 Byte	Calculated according to <i>Algorithm 1</i> [TABLE-2]
		TIMESTAMP	2 nd Byte – 9 th Byte	8 Bytes	ts
		DATA_LEN	10 th Byte- 11 th Byte	2 Bytes	$length(D_{Cipher}[J])$
		DATA	12 th Byte onwards	$length(D_{Cipher}[J])$	$D_{Cipher}[J]$
		SIGNATURE-ALIAS	[11+length(D _{cipher})]- th Byte onwards	VARIABLE	S
Transport Layer	11	The <i>OSL</i> layer packet is forwarded to the Transport layer. Since the packet comes from the <i>OSL</i> , it is processed by the augmentation logic of transport layer. A <i>TCP</i> packet is created encapsulating the <i>OSL</i> packet as payload.			
	12	The value of the digest function is calculated for the <i>TCP</i> header bytes Outcome of this step: $h:=g(TCP\ header\ bytes)$			
	13	Bytes of the field <i>DATA_LEN</i> (i.e. the 4 th field) are encrypted with the symmetric key h . FOR $J=0$ to $D_{Cipher}.length$ $D_{Cipher}[J] := E(D_{Cipher}[J], h)$ Next J			
	14	The TCP packet is transferred to the layer below, i.e. the <i>Network Layer</i>			

ALGORITHM 8.1: ENCRYPTION OF THE DATA BYTES AT THE OSL LAYER

INPUT	a. $D[]$ b. R c. Z_1 d. Z_2
STEP	$D_{Cipher} := \text{new byte}[D.length]$ FOR $I=0$ To $D.length$ $D_{Cipher}[I] := D[I] \oplus (R \bmod 2 == 0 \text{ AND } I \bmod 2 == 0) ? Z_1 : Z_2$ NEXT I
Output	D_{Cipher}

Table 9. Algorithm 9

Algorithm 9: Processing of Data Packets and Decryption Technique at the Receiver's VIS		
TRANSPORT <		

S L L A Y E R		<ul style="list-style-type: none"> ▪ Data field bytes (D[]) ▪ The Signature Alias (S)
	8	Decrypt the value of the Signature Alias with the Sender's public key. Outcome of this step: R := E_{+Sender}(S)
	10	Compute the value of the magnitude (Positive value of the amplitude) of the Sine Wave. Outcome of this step: $Y_s := A \sin \frac{2\pi}{\lambda} (c * f(t) - x) $ where t= ts, & A, λ have already been exchanged in earlier phases <i>c = 3 = 3x10⁸/10⁸ = [the velocity of light in vacuum space expressed in m-sec⁻¹ / 10⁸]</i>
	10	The p-function of the wavelength of the above Sine wave is calculated Outcome of this step: W = p(λ)
	11	Two one-time key-aliases (Z₁ and Z₂) are calculated with R , Y_s and W . Outcome of this step: Z₁ := R Φ Y_s and Z₂ := R Φ W
	12	IF R mod 2==0 THEN Symmetrically decrypt even bytes of D[] with Z₁ and odd bytes with Z₂ <div style="text-align: right;">(As per Algorithm 8.1 [Table-8])</div> ELSE Symmetrically decrypt odd bytes of D[] with Z₁ and even bytes with Z₂ <div style="text-align: right;">(As per Algorithm 8.1 [Table-8])</div> END IF Outcome of this step: The final and plain data bytes Dplaint[] <div style="text-align: center;">This data is delivered at the NAS</div>

ALGORITHM 9.1: EXTRACT BYTES OF THE DATA FIELD

Input: The *OSL DATA PACKET* Bytes (**P[]**)

1	X : = Value of the 10 th and 11 th Bytes
2	Since DATA_LEN field consists of the 10 th and 11 th bytes of this packet, the value of the field DATA-LEN:=X
3	First 11 bytes accommodate the fields PACKET TYPE (1 BYTE), TIMESTAMP (11 BYTES) and DATA-LEN (2 BYTES). So, the <i>DATA FIELD</i> starts from the 12 th bytes onwards and continue till next <i>DATA-LEN</i> bytes.
4	Hence, the data bytes are obtained as: D[] : = new byte[X] FOR J=0 TO X

	$D[J] := P[J + 11]$ NEXT J
--	--------------------------------------

Table 10. String Parsing Algorithms

Algorithm 3.1. String Generation

1. There is a common DELIMITER which both client and server know of
2. Input: N number of strings, where $N \in \mathbb{I}^+$, DELIMITER
3. resultString:= “ ” // EMPTY String
4. **For** I=0 **to** N-1
 - resultString := **concat**(resultString, DELIMITER, Ith String)
- Next I
5. **Output**:= resultString

Algorithm-3.2: String Extraction Algorithm

Table-11: Algorithm-12

ALGORITHM 12: Check if inbound TCP Packet is an OSL packet	
Input	A TCP Packet, it's header and payload bytes (H[] and P[])
1	$V :=$ The value of the first byte of the payload = P[0]
2	$T_s :=$ Long value of next 8 bytes = longValue(P[1], P[2], P[3], P[4], P[5], P[6], P[7], P[8])
3	$M := T_s \bmod 32$
4	$B_M := \text{toBinary}(M) \equiv \{b_4 b_3 b_2 b_1 b_0\}$
5	$B_V := \text{toBinary}(V) \equiv \{B_7 B_6 B_5 B_4 B_3 B_2 B_1 B_0\}$
6	IF (first 5 bits from the LSB of B_M and B_V match) THEN $X := \text{toDecimal}(B_7 B_6 B_5)$ IF ($X \geq 0$ AND $X \leq 4$) THEN Output: The packet is an OSL Packet of Type X ELSE Output: The packet is not an OSL packet END-IF ELSE Output: The packet is not an OSL packet END-IF

Table-12: Legends and Significance of terms

Serial No.	Term/Legend	Description
1	VIS	Virtual Internetworking Stack
2	OSL (also, OSL layer)	Opaque Security Layer
3	Client	The VIS of a host that invites another VIS to communicate
4	Server	VIS which is invited by the client VIS
5	E_{+Server}(X)	Encrypt/Decrypt X with the public key of the Server
6	E_{-Server}(X)	Decrypt/Encrypt X with the private key of the Server
7	QR(aText)	Create a QR code off the String, aText
8	QR⁻¹(Q)	Decode a QR code and get the text
9	Rand() or Random()	Generate a positive, random integer
10	toBinary(x)	Convert a byte x (in decimal) to its binary equivalent
11	colorOf(img)/getColor(img)	Get the color of an image, all of whose pixels have same color (ARGB)
12	Length(Q[]) / Len(Q[])	Number of elements of the array, Q

2.5 Illustrations of sample packets

Results and reports of the experiments carried out with the implementation of the VIS security model were duly logged. A few samples of the OSL packets are presented in this section. [Table-23] shows a *SESSION REQUEST* Packet while the tables [Table-24] to [Table-27] present the four other types of packets defined by the OSL. We analyze the bytes of the *SESSION REQUEST* packet presented in [Table-23]. The first byte of any of the five OSL packets represents the type of the packet, while the bytes 2nd to 9th represent the 8-byte timestamp. The timestamp bytes, {0, 0, 1, 66, 39,-70,-11,-31} represent the value 1383646033377 which is indicative of “**Tue Nov 05 15:37:13 IST 2013**”. The packet-type field in [Table-23] contains the value 1. Since the 5 LSBs contain the value: $1383646033377 \bmod 32 = 1$, whereas the 3 MSBs contain the raw initial identifier assigned to the packet type (i.e. 0 here); the value of the first field is computed to be $(000\ 00001)_2 = 1$.

Similarly, the value of the first byte of the challenge packet, shown in [Table-24] can be computed to be $(001\ 00001)_2 = 33$, according to *Algorithm 1* [Table-2]

The public and private keys of the Server-side VIS that corresponds to performance analysis described in Sec. 3.3 are shown in [Table-28]. Samples of the color QR codes generated during creation of a *SESSION REQUEST* packet and creation of an OSL *CHALLENGE* packet, as described in *Algorithm 2* in [Table-3] and *Algorithm 3* in [Table-4] are presented in [Figure-14].

2.6 Encapsulation of the OSL packets

The *OSL* layer packets are, however, encapsulated within a *TCP* packet. The *TCP* packet is encapsulated within an *IP* datagram and finally an *IP* datagram is encapsulated in a Link layer frame, as shown in [Figure 13].

[Figure-15] shows the analysis of the headers belonging to the Transport layer, the Network Layer and the Link Layer (*shown as an Ethernet header*)

Fig.8: Effective Cipher Speed versus Data Size

Fig. 9: SSL Cipher speed versus Data Size

3 Performance analysis of the security model

Fig.5 : Processing time in in Receiver Transport Layer

The security model of the Networking stack envisaged in this thesis, was implemented both on a *Linux Kernel* and on a *Microsoft Windows* Operating System. While the implementation was experimentally found to be responsive and scalable, every single event in the *VIS* implementation was *logged* for analysis of its performance and

comparison of the security model with *SSL* version 2. [Table-13] illustrates the processing performance of a *SESSION REQUEST* packet at a Sender-side *VIS* equipped with a 1.2 GHz dual Core processor and 2 GB of physical memory. Though the *LOG* contained about a million of records, the tables provided here have been abridged. Before presenting these tables and relevant graphs, however, the integrity of the entire *LOG* with the abridged set of results presented with this article has been duly verified. In [Table-13] we find that a *SESSION REQUEST* packet has an average processing time of 1,400 μ sec and 400 μ sec at the *OSL* layer and the Transport Layer, respectively, in a *VIS* running on a 1.2 GHz dual core processor and 2 GB of *RAM*. It is interesting to note that the standard deviation at the Transport Layer is **ZERO** while the standard deviation at the *OSL* layer is 917.7 μ sec. This is due to the fact that *OSL* layer deals with generation of QR codes; and the time required to generate QR codes off different texts varies by considerably. Since the transport layer encrypts almost some fixed number of bytes with a symmetric key, $h = g(\text{TCP header})$ while processing a *SESSION REQUEST* packet as described in Algorithm 2 [Table 3], the process exhibits a standard deviation equal to zero μ sec.

Fig. 6 : Processing Time of packets in Receiver VIS

[Table-14], which shows the processing of a *SESSION REQUEST* packet at a Receiver-side *VIS*, also suggests a zero standard deviation at the transport layer. The processing of three other types of *OSL* packets used during the establishment of a secure session, are illustrated in the [Tables 15-20]. All the tables here are suggestive of consistent performance in the augmented transport layer. The variation of performance time in the *OSL* layer, however, is acceptable as the standard deviation never exceeded 600 μ sec in average. Processing time of the five types of *OSL* packets in the Sender-side *OSL* layer and the sender-side transport layer are plotted in the graphs as shown in [Figure-3] and [Figure-4], respectively. Also, [Figure-5] and [Figure-6] present the processing time of these packets in the Transport layer and the *OSL* layer, respectively, of a receiver-side *VIS*.

Fig.4 : Processing time in Sender Transport Layer

Fig.3 Processing Time at Sender VIS

Table-13: Processing time of the *Session Request* packet in a sender-side *VIS*

Packet type (Most significant 3 bits)	(DOWNWARDS THE STACK) TIMESTAMP IN THE <i>VIS</i>			Elapsed Time interval (Δt) in milliseconds		Processing Time in μ sec = Δt - Logging Delay (0.6 milliseconds)	
	Application Layer	OSL Layer	Transport Layer	OSL Layer	Transport Layer	OSL Layer	Transport Layer
0x00	1,383,544,080,111	1,383,544,080,113	1,383,544,080,114	2	1	1,400.0	400.0
0x00	1,383,544,080,111	1,383,544,080,112	1,383,544,080,113	1	1	400.0	400.0
0x00	1,383,544,080,111	1,383,544,080,112	1,383,544,080,113	1	1	400.0	400.0
0x00	1,383,544,080,111	1,383,544,080,114	1,383,544,080,115	3	1	2,400.0	400.0
0x00	1,383,544,080,111	1,383,544,080,112	1,383,544,080,113	1	1	400.0	400.0
0x00	1,383,544,080,111	1,383,544,080,114	1,383,544,080,115	3	1	2,400.0	400.0
0x00	1,383,544,080,111	1,383,544,080,114	1,383,544,080,115	3	1	2,400.0	400.0
0x00	1,383,544,080,111	1,383,544,080,112	1,383,544,080,113	1	1	400.0	400.0
0x00	1,383,544,080,111	1,383,544,080,113	1,383,544,080,114	2	1	1,400.0	400.0
0x00	1,383,544,080,111	1,383,544,080,112	1,383,544,080,113	1	1	400.0	400.0
0x00	1,383,544,080,111	1,383,544,080,112	1,383,544,080,113	1	1	400.0	400.0
0x00	1,383,544,080,112	1,383,544,080,113	1,383,544,080,114	1	1	400.0	400.0
0x00	1,383,544,080,112	1,383,544,080,115	1,383,544,080,116	3	1	2,400.0	400.0
0x00	1,383,544,080,112	1,383,544,080,115	1,383,544,080,116	3	1	2,400.0	400.0
0x00	1,383,544,080,112	1,383,544,080,113	1,383,544,080,114	1	1	400.0	400.0
0x00	1,383,544,080,112	1,383,544,080,115	1,383,544,080,116	3	1	2,400.0	400.0
0x00	1,383,544,080,112	1,383,544,080,115	1,383,544,080,116	3	1	2,400.0	400.0
0x00	1,383,544,080,112	1,383,544,080,115	1,383,544,080,116	3	1	2,400.0	400.0
0x00	1,383,544,080,112	1,383,544,080,115	1,383,544,080,116	3	1	2,400.0	400.0
0x00	1,383,544,080,112	1,383,544,080,114	1,383,544,080,115	2	1	1,400.0	400.0
				Average		1400	400
				STD.		917.7	0.0

- The results here correspond to a *VIS* running on a 1.2 GHZ dual core processor and 2 GB memory.

Table-14: Processing time of *SESSION REQUEST* packet at a RECEIVER-SIDE *VIS*

Packet Type	Entry time timestamp in the stack			Elapsed Time interval (Δt) in milliseconds		Processing Time in μ sec = Δt - Logging Delay (0.6 milliseconds)	
	Transport Layer	OSL Layer	Application Layer	Transport Layer	OSL Layer	Transport Layer	VNS Layer
3 most significant bits							
0x00	1,383,544,234,504	1,383,544,234,505	1,383,544,234,507	1	2	400.00	1,400.00
0x00	1,383,544,234,504	1,383,544,234,505	1,383,544,234,506	1	1	400.00	400.00
0x00	1,383,544,234,506	1,383,544,234,507	1,383,544,234,509	1	2	400.00	1,400.00
0x00	1,383,544,234,504	1,383,544,234,505	1,383,544,234,506	1	1	400.00	400.00
0x00	1,383,544,234,504	1,383,544,234,505	1,383,544,234,506	1	1	400.00	400.00
0x00	1,383,544,234,506	1,383,544,234,507	1,383,544,234,508	1	1	400.00	400.00
0x00	1,383,544,234,506	1,383,544,234,507	1,383,544,234,508	1	1	400.00	400.00
0x00	1,383,544,234,506	1,383,544,234,507	1,383,544,234,508	1	1	400.00	400.00
0x00	1,383,544,234,505	1,383,544,234,506	1,383,544,234,508	1	2	400.00	1,400.00
0x00	1,383,544,234,506	1,383,544,234,507	1,383,544,234,508	1	1	400.00	400.00
0x00	1,383,544,234,504	1,383,544,234,505	1,383,544,234,507	1	2	400.00	1,400.00
0x00	1,383,544,234,504	1,383,544,234,505	1,383,544,234,506	1	1	400.00	400.00
0x00	1,383,544,234,504	1,383,544,234,505	1,383,544,234,506	1	1	400.00	400.00
0x00	1,383,544,234,504	1,383,544,234,505	1,383,544,234,507	1	2	400.00	1,400.00
0x00	1,383,544,234,506	1,383,544,234,507	1,383,544,234,508	1	1	400.00	400.00
0x00	1,383,544,234,505	1,383,544,234,506	1,383,544,234,508	1	2	400.00	1,400.00
0x00	1,383,544,234,507	1,383,544,234,508	1,383,544,234,510	1	2	400.00	1,400.00
0x00	1,383,544,234,507	1,383,544,234,508	1,383,544,234,510	1	2	400.00	1,400.00
0x00	1,383,544,234,505	1,383,544,234,506	1,383,544,234,507	1	1	400.00	400.00
0x00	1,383,544,234,505	1,383,544,234,506	1,383,544,234,507	1	1	400.00	400.00
				Average		400.00	800.00
				STD.		0	502.6247

**Fig, 10: Cipher speed versus Data size
(Comparison curve)**

3.1 Comparison with the performance of SSL

The author carried out real time experiments to compare the performance of the security model to the performance of *SSL* version 2. [Figure-8] and [Figure-9] show the Ciphering-speed (*MB/sec*) versus data size (*Bytes*) graphs obtained with the same set of data processed by, a *VIS* implementation and the *Secure Socket Layer (SSL* version 2), respectively. In order to avoid performance lags due to heterogeneity of Hardware (like, Processor speed, memory etc.), same Hardware configuration was used while carrying out the experiments for this comparison. [Figure-10] presents the graphs for both *VIS* and *SSL* together. The results, however, proved the supremacy of the *SSL* over the *VIS* security model envisaged in this thesis as far as speed was concerned. But, the little bit of performance lag of the *VIS* model is acceptable for situations where security and flexibility demand more *proprietary-ness* than just performance. A secured system is secure as long as its architecture is not exposed to the world. Sometimes, we trust neither our *ISP* nor anybody else, depending on the sensitivity of the information that we communicate over Internet. Defense and Intelligence Bureau of a country cannot trust an *ISP* and there must be sniffers all around. Routers, for example, pass IP datagrams across the Internet and some of these routers might have some intention or other to sniff packets from a particular source. The model proposed in this thesis is strongly recommended to befool these *evil* routers and gateways. As appears to these sniffers, all packets from a *VIS* host are just valid IP datagram. If a gateway pushes these datagrams upward its TCP/IP stack to make out something meaningful, it will simply fail; because, its Internetworking stack is a standard stack and does not comply with the *OSL* and the *augmented* transport layer of the *VIS* model.

3.2 Flexibility and opacity provided by the proposed VIS model

In the *VIS* model discussed in this thesis, flexibility and opacity go hand-in-hand. The thesis recommends just a security model and not a standard, concrete implementation. It strongly prescribes proprietary security mechanisms in sectors such as Defense, space research, agencies dealing with highly valuable and viable *IPR* documents. The *VIS* offers the flexibility of Internetworking because it does not dig up the Network layer, lest the flexibility of Internetworking is lost. On the other hand, opacity prevails in the transport layer onwards. So, as appears to an *evil router* or a compromised *gateway*, the Network layer seems to deal with valid *IP* datagrams but the augmented rules injected in the transport layer and introduction of a proprietary *OSL* layer in the *VIS* make it very difficult for the sniffers and a *Man-In-Middle* attacker to succeed. The *VIS* itself is very flexible to offer proprietary security, because it suggests **what to do, but not how to achieve** the ciphering techniques. An organization that might use this *VIS* security model, need not adhere to any strict cryptographic algorithm; rather any standard and/or proprietary cryptographic technique or a permutation of techniques can be used.

The maximum degree of flexibility is offered towards using a third party software. The introduction of the *OSL* layer and the augmentation of the *transport layer* and their respective functional architecture need not be revealed to a third party software vendor. This is an added advantage to a software vendor consulted for rapid development of an application software plus it does not require an Organization to trust and compromise the proprietary security mechanism to a third party vendor.

3.3 Network Access Point

All the applications running on an Operating System do not require same level of security. For example, one becomes more concerned about cyber security while Internet-banking than while on a casual chat for social networking. The *VIS* security model was conceptualized keeping this in mind. An employee of an organization that uses the *VIS* security model, may use an application on her computer which demands lesser security on the Internet than certain organizational applications. *NAP* (*Network Access Point*) is basically a service access point offered by the *OSL* layer. [Figure-11] shows the logical position of the *Network Access Point (NAP)* in a *Virtual Internetworking Stack*.

All the applications that need to access Network must tap-in here to access the *Virtual Internet Stack*. The transport layer of the *VIS* is such augmented that:

- a) In the *sender*-side, packet that come down from the *OSL* layer must be processed by the augmented transport layer logic. All the packets that come directly from the application layer, are not processed by the *augmentation logic* and are forwarded down to the standard transport layer of the TCP/IP stack.
- b) In the *receiver*-side, packets that are recognized by the transport layer to belong to any of the five packet types defined by the *OSL*, are processed accordingly by the augmented transport layer logic and are handed over to the *OSL* layer. Otherwise, a normal (*Non-OSL* type) packet is processed by the standard transport layer logic of the TCP/IP stack and are handed over directly to the application layer.

Network Access Point is a Service Access Point that filters unwanted applications and deny service to a non-authenticated application. Three important rules to note about an *NAP* are:

- a) It offers Network service to the applications that need to access network over the *VIS* model. All the applications that needs to use *VIS* must hook-onto the *NAP*.

Algorithm 10 [Table-21] shows how a packet is processed at the *NAP* in a *VIS*.

[Figure-12] illustrates the abstraction provided by the *OSL* and the role of an *NAP*.

- b) It authenticates an application that seeks to avail network access. If authentication fails it can *either* allow Internet connection over standard TCP/IP stack, *or can deny any network access*. These rules, however, may be set by the system administrator of an organization as the organizational policies demand.

If authentication succeeds, it allows an application to use and communicate over the *VIS* security model.

Algorithm 11 [Table-21] shows how an application is authenticated at the *NAP* for being granted access to the *VIS* model.

- c) *It is very important to note that an application cannot access the standard TCP/IP stack and the Virtual Internetworking Stack simultaneously. If an application is already using the VIS, all the communication it makes over the Internet must be via VIS only.*

LOGICAL POSITION OF THE *NETWORK ACCESS POINT* IN A VIS

Fig.11: Posotion of the NAP inside VIS

THE ABSTRACTION PROVIDED BY THE OSL Layer and the NAP

Fig.12: Abstraction provided by the NAP in a VIS

Table-21. Network Access Point and Packet Processing in a VIS

ALGORITHM 10: PROCESSING OF PACKET AT THE SENDER-SIDE VIS	
APPLICATION LAYER	Application Layer generates Application data to be sent across Internet
NETWORK ACCESS POINT	<p>IF (App needs VIS) THEN</p> <ul style="list-style-type: none"> ▪ App hooks onto the Network Access Point ▪ Network Access Point must Authenticate the App's signature [Algorithm 11] ▪ IF (Authentication Successful) THEN The Application Data is passed to the OSL Layer ELSE The Network Access (VIS) is denied END-IF <p>ELSE</p> <ul style="list-style-type: none"> ▪ The Application Data is directly passed to the Transport Layer <p>END-IF</p>
OSL LAYER	<p>OSL-Layer processing takes place.</p> <p>EITHER A secure connection is set up following the 4-phase session establishment</p> <p>OR Data communication takes place over an already established secure session</p> <p>The OSL packets are handed over to the Transport Layer in both the cases above.</p>
TRANSPORT LAYER	<p>The Transport layer receives a packet</p> <p>IF (The packet comes from the OSL Layer) THEN</p> <ul style="list-style-type: none"> ▪ Process the OSL Packet using augmentation logic <p>ELSE</p> <ul style="list-style-type: none"> ▪ Process the normal application layer data according to a standardization of a normal TCP/IP stack <p>END-IF</p> <p>Pass the TCP packet to the layer below, i.e. the Network Layer</p>
Network Layer	The Network layer has no clue as to the upper layers and that is why Internetworking is not disturbed

ALGORITHM 11: Authentication of an application at the NETWORK ACCESS POINT (NAP)	
1	The NAP maintains an updatable database of the applications that are authorized (by the administrator of the organization) to access the VIS, as shown in [Table-22]
2	The application that seeks to use the VIS security model, passes its UUID together with the application name, vendor, version encrypted with the a private key maintained by the application.
3	The NAP receives the request which consists of two parts a) The Application UUID (this_App_ID) b) Some encrypted bytes(C[])
4	The NAP looks up [Table-22] to fetch all relevant information against this application id Pseudo code: select * from [Table-22] where Appliction_UUID='<this_App_ID>'
5	The NAP decrypts the byte array (C[]) with the Application specific public key fetched in the previous step
6	IF (the information and the decrypted texts match exactly) THEN App is AUTHENTICATED and authorized to use the VIS security model ELSE The App is not authenticated and denied VIS service END-IF

ENCAPSULATION OF THE OSL PACKETS

Fig. 13 : Encapsulation of OSL Packets

Fig.14: Samples of Color QR codes

Fig.15: Layerwise Analysis of Headers down the Virtual Internetworking Stack

3.3.2 Benefits of NAP: Let us assume that a computer in an organization runs a number of applications among which only the applications *A* and *X* are compatible to the *VIS* model. We also assume that *X* is developed by a vendor who had some intention or other to write some *Trojans* to leak out some information. Initially the applications *A* and *X* are allowed to access the Network, because they are both authenticated and authorized to access the *VIS*. Now, the *Application-X* has some *Trojan* codes that were intended to leak out certain information from the computer to a remote *enemy* server. While *Application-X* executes as desired, in background it keeps sending certain information to a remote enemy server.

But, since it is hooked onto the *NAP* to access the *VIS*, all the communication application-*X* can make across Internet, must be as per the *VIS*. Now, the enemy server that expects some information the spyware, cannot find anything meaningful at all; because, this server uses a TCP/IP stack which does not comply with a *VIS* communication. *Trojans* attacks in a *VIS* model thus run into vain.

4 Results:

Table-15. Processing time of the challenge packet in the sender-side VIS

Packet Type	(DOWNWARD THE STACK) TIMESTAMP IN THE VIS			Elapsed Time interval (Δt) in milliseconds		Processing Time in μ sec = Δt - Logging Delay (0.6 milliseconds)	
3 MSBs	Application Layer	OSL Layer	Transport Layer	OSL Layer	Transport Layer	OSL Layer	Transport Layer
0x01	1,383,544,840,322	1,383,544,840,323	1,383,544,840,325	1	2	400	1400
0x01	1,383,544,840,322	1,383,544,840,326	1,383,544,840,327	4	1	340 0	400
0x01	1,383,544,840,322	1,383,544,840,323	1,383,544,840,324	1	1	400	400
0x01	1,383,544,840,322	1,383,544,840,326	1,383,544,840,328	4	2	340 0	1400
0x01	1,383,544,840,322	1,383,544,840,324	1,383,544,840,325	2	1	140 0	400
0x01	1,383,544,840,322	1,383,544,840,323	1,383,544,840,325	1	2	400	1400
0x01	1,383,544,840,322	1,383,544,840,325	1,383,544,840,327	3	2	240 0	1400
0x01	1,383,544,840,323	1,383,544,840,324	1,383,544,840,325	1	1	400	400
0x01	1,383,544,840,323	1,383,544,840,325	1,383,544,840,326	2	1	140 0	400
0x01	1,383,544,840,323	1,383,544,840,324	1,383,544,840,325	1	1	400	400
0x01	1,383,544,840,323	1,383,544,840,326	1,383,544,840,327	3	1	240 0	400
0x01	1,383,544,840,323	1,383,544,840,325	1,383,544,840,327	2	2	140 0	1400
0x01	1,383,544,840,323	1,383,544,840,325	1,383,544,840,327	2	2	140 0	1400
0x01	1,383,544,840,323	1,383,544,840,326	1,383,544,840,327	3	1	240 0	400
0x01	1,383,544,840,323	1,383,544,840,325	1,383,544,840,326	2	1	140 0	400
0x01	1,383,544,840,323	1,383,544,840,324	1,383,544,840,325	1	1	400	400
0x01	1,383,544,840,323	1,383,544,840,324	1,383,544,840,325	1	1	400	400
0x01	1,383,544,840,323	1,383,544,840,327	1,383,544,840,328	4	1	340 0	400
0x01	1,383,544,840,323	1,383,544,840,327	1,383,544,840,328	4	1	340 0	400
0x01	1,383,544,840,323	1,383,544,840,327	1,383,544,840,328	4	1	340 0	400

				Average		170 0	700
				STD.		120 0	500

Table 16. PROCESSING TIME OF THE CHALLENGE PACKET IN THE RECEIVER-SIDE VIS

Packet Type		UPWARD THE STACK TIMESTAMP IN RECEIVER-VIS		Elapsed Time interval (Δt) in milliseconds		Processing Time (in μ sec) = Δt - Logging Delay (0.6 milliseconds)	
3 MSB	Transport Layer	OSL Layer	Application Layer	Transport Layer	OSL Layer	Transport Layer	OSL Layer
0x01	1,383,544,884,133	1,383,544,884,134	1,383,544,884,135	1	1	400.0	400.0
0x01	1,383,544,884,133	1,383,544,884,136	1,383,544,884,138	3	2	2,400.0	1,400.0
0x01	1,383,544,884,133	1,383,544,884,134	1,383,544,884,136	1	2	400.0	1,400.0
0x01	1,383,544,884,133	1,383,544,884,134	1,383,544,884,135	1	1	400.0	400.0
0x01	1,383,544,884,133	1,383,544,884,134	1,383,544,884,135	1	1	400.0	400.0
0x01	1,383,544,884,133	1,383,544,884,134	1,383,544,884,136	1	2	400.0	1,400.0
0x01	1,383,544,884,133	1,383,544,884,134	1,383,544,884,135	1	1	400.0	400.0
0x01	1,383,544,884,133	1,383,544,884,134	1,383,544,884,136	1	2	400.0	1,400.0
0x01	1,383,544,884,133	1,383,544,884,135	1,383,544,884,136	2	1	1,400.0	400.0
0x01	1,383,544,884,133	1,383,544,884,135	1,383,544,884,137	2	2	1,400.0	1,400.0
0x01	1,383,544,884,133	1,383,544,884,134	1,383,544,884,136	1	2	400.0	1,400.0
0x01	1,383,544,884,133	1,383,544,884,135	1,383,544,884,136	2	1	1,400.0	400.0
0x01	1,383,544,884,133	1,383,544,884,134	1,383,544,884,135	1	1	400.0	400.0
0x01	1,383,544,884,134	1,383,544,884,137	1,383,544,884,138	3	1	2,400.0	400.0
0x01	1,383,544,884,134	1,383,544,884,135	1,383,544,884,136	1	1	400.0	400.0
0x01	1,383,544,884,134	1,383,544,884,135	1,383,544,884,136	1	1	400.0	400.0
0x01	1,383,544,884,134	1,383,544,884,137	1,383,544,884,138	3	1	2,400.0	400.0
0x01	1,383,544,884,134	1,383,544,884,136	1,383,544,884,137	2	1	1,400.0	400.0
0x01	1,383,544,884,134	1,383,544,884,137	1,383,544,884,138	3	1	2,400.0	400.0
0x01	1,383,544,884,134	1,383,544,884,135	1,383,544,884,136	1	1	400.0	400.0
				Average		1000	700
				STD.		800.0	458.3

Table 17. Processing Time of the *Response Packet* in the Sender-SIDE *VIS*

Packet Type	TIMESTAMP IN VIS (DOWNWARD THE STACK)			Elapsed Time interval (Δt) in milliseconds		Processing Time in μ sec = Δt - Logging Delay (0.6 milliseconds)	
	Application Layer	VNS Layer	Transport Layer	VNS Layer	Transport Layer	VNS Layer	Transport Layer
0x02	1,383,545,045,982	1,383,545,045,983	1,383,545,045,984	1	1	400.0	400.0
0x02	1,383,545,045,982	1,383,545,045,983	1,383,545,045,984	1	1	400.0	400.0
0x02	1,383,545,045,982	1,383,545,045,983	1,383,545,045,984	1	1	400.0	400.0
0x02	1,383,545,045,982	1,383,545,045,985	1,383,545,045,986	3	1	2,400.0	400.0
0x02	1,383,545,045,982	1,383,545,045,984	1,383,545,045,986	2	2	1,400.0	1,400.0
0x02	1,383,545,045,982	1,383,545,045,983	1,383,545,045,984	1	1	400.0	400.0
0x02	1,383,545,045,982	1,383,545,045,985	1,383,545,045,987	3	2	2,400.0	1,400.0
0x02	1,383,545,045,982	1,383,545,045,983	1,383,545,045,984	1	1	400.0	400.0
0x02	1,383,545,045,982	1,383,545,045,984	1,383,545,045,986	2	2	1,400.0	1,400.0
0x02	1,383,545,045,983	1,383,545,045,986	1,383,545,045,987	3	1	2,400.0	400.0
0x02	1,383,545,045,983	1,383,545,045,986	1,383,545,045,987	3	1	2,400.0	400.0
0x02	1,383,545,045,983	1,383,545,045,984	1,383,545,045,985	1	1	400.0	400.0
0x02	1,383,545,045,983	1,383,545,045,986	1,383,545,045,987	3	1	2,400.0	400.0
0x02	1,383,545,045,983	1,383,545,045,985	1,383,545,045,986	2	1	1,400.0	400.0
0x02	1,383,545,045,983	1,383,545,045,984	1,383,545,045,985	1	1	400.0	400.0
0x02	1,383,545,045,983	1,383,545,045,984	1,383,545,045,986	1	2	400.0	1,400.0
0x02	1,383,545,045,983	1,383,545,045,985	1,383,545,045,986	2	1	1,400.0	400.0
0x02	1,383,545,045,983	1,383,545,045,986	1,383,545,045,987	3	1	2,400.0	400.0
				Average		1242.1	610.5263
				STD.		874.4	407.7

Table-18. Processing time of the *response packet* in the receiver-side

Packet Type (3 MSBs)	TIMESTAMP IN THE VIS (UPWARD THE STACK)			Elapsed Time interval (Δt) (in milliseconds)		Processing Time (in μ sec) = Δt - Logging Delay (0.6 milliseconds)	
	Transport Layer	OSL Layer	Application Layer	Transport Layer	OSL Layer	Transport Layer	OSL Layer
0x02	1,383,545,061,227	1,383,545,061,228	1,383,545,061,230	1	2	400	1400
0x02	1,383,545,061,227	1,383,545,061,229	1,383,545,061,230	2	1	1400	400
0x02	1,383,545,061,227	1,383,545,061,228	1,383,545,061,230	1	2	400	1400
0x02	1,383,545,061,227	1,383,545,061,229	1,383,545,061,230	2	1	1400	400
0x02	1,383,545,061,227	1,383,545,061,228	1,383,545,061,230	1	2	400	1400
0x02	1,383,545,061,227	1,383,545,061,228	1,383,545,061,229	1	1	400	400
0x02	1,383,545,061,227	1,383,545,061,228	1,383,545,061,229	1	1	400	400
0x02	1,383,545,061,227	1,383,545,061,228	1,383,545,061,229	1	1	400	400
0x02	1,383,545,061,227	1,383,545,061,229	1,383,545,061,230	2	1	1400	400
0x02	1,383,545,061,228	1,383,545,061,229	1,383,545,061,230	1	1	400	400
0x02	1,383,545,061,228	1,383,545,061,230	1,383,545,061,232	2	2	1400	1400
0x02	1,383,545,061,228	1,383,545,061,230	1,383,545,061,231	2	1	1400	400
0x02	1,383,545,061,228	1,383,545,061,229	1,383,545,061,231	1	2	400	1400
0x02	1,383,545,061,228	1,383,545,061,229	1,383,545,061,230	1	1	400	400
0x02	1,383,545,061,228	1,383,545,061,229	1,383,545,061,231	1	2	400	1400
0x02	1,383,545,061,228	1,383,545,061,229	1,383,545,061,231	1	2	400	1400
0x02	1,383,545,061,228	1,383,545,061,229	1,383,545,061,230	1	1	400	400
0x02	1,383,545,061,228	1,383,545,061,230	1,383,545,061,231	2	1	1400	400
0x02	1,383,545,061,228	1,383,545,061,230	1,383,545,061,232	2	2	1400	1400
0x02	1,383,545,061,228	1,383,545,061,229	1,383,545,061,231	1	2	400	1400
			AVERAGE=			750	850
			STANDARD DEVIATION=			489.36	510.42

Table-19:
Processing time of OSL acknowledgement packet in the sender-side V/S

Packet Type	(DOWNWARD THE STACK) TIMESTAMP IN V/S			Elapsed Time interval (Δt) in milliseconds		Processing Time in μ sec = Δt - Logging Delay (0.6 milliseconds)	
3 MSB	Application Layer	OSL Layer	Transport Layer	OSL Layer	Transport Layer	OSL Layer	Transport Layer
0x03	1,383,545,534,153	1,383,545,534,155	1,383,545,534,156	2	1	1,400.0	400.0
0x03	1,383,545,534,153	1,383,545,534,154	1,383,545,534,155	1	1	400.0	400.0
0x03	1,383,545,534,153	1,383,545,534,154	1,383,545,534,156	1	2	400.0	1,400.0
0x03	1,383,545,534,153	1,383,545,534,154	1,383,545,534,156	1	2	400.0	1,400.0
0x03	1,383,545,534,154	1,383,545,534,155	1,383,545,534,157	1	2	400.0	1,400.0
0x03	1,383,545,534,154	1,383,545,534,155	1,383,545,534,157	1	2	400.0	1,400.0
0x03	1,383,545,534,154	1,383,545,534,157	1,383,545,534,158	3	1	2,400.0	400.0
0x03	1,383,545,534,154	1,383,545,534,155	1,383,545,534,156	1	1	400.0	400.0
0x03	1,383,545,534,154	1,383,545,534,156	1,383,545,534,157	2	1	1,400.0	400.0
0x03	1,383,545,534,154	1,383,545,534,156	1,383,545,534,157	2	1	1,400.0	400.0
0x03	1,383,545,534,154	1,383,545,534,156	1,383,545,534,158	2	2	1,400.0	1,400.0
\0x03	1,383,545,534,154	1,383,545,534,155	1,383,545,534,156	1	1	400.0	400.0
0x03	1,383,545,534,154	1,383,545,534,155	1,383,545,534,156	1	1	400.0	400.0
0x03	1,383,545,534,154	1,383,545,534,155	1,383,545,534,157	1	2	400.0	1,400.0
0x03	1,383,545,534,154	1,383,545,534,155	1,383,545,534,157	1	2	400.0	1,400.0
0x03	1,383,545,534,154	1,383,545,534,157	1,383,545,534,158	3	1	2,400.0	400.0
0x03	1,383,545,534,154	1,383,545,534,155	1,383,545,534,156	1	1	400.0	400.0
0x03	1,383,545,534,154	1,383,545,534,155	1,383,545,534,157	1	2	400.0	1,400.0
0x03	1,383,545,534,154	1,383,545,534,155	1,383,545,534,157	1	2	400.0	1,400.0
0x03	1,383,545,534,154	1,383,545,534,156	1,383,545,534,157	2	1	1400.0	400.0
				Average		821.05	873.6842
				STD.		674.00	499.3000

TABLE 20:
Processing time of *OSL acknowledgement* packet in the receiver-side *VIS*

Packet Type	(UPWARD THE STACK) TIMESTAMP IN <i>VIS</i>			Elapsed Time interval (Δt) in milliseconds		Processing Time in μ sec = Δt - Logging Delay (0.6 milliseconds)	
	Transport Layer	<i>OSL</i> Layer	Application Layer	Transport Layer	<i>OSL</i> Layer	Transport Layer	<i>OSL</i> Layer
0x03	1,383,545,579,407	1,383,545,579,409	1,383,545,579,410	2	1	1,400.0	400.0
0x03	1,383,545,579,407	1,383,545,579,409	1,383,545,579,410	2	1	1,400.0	400.0
0x03	1,383,545,579,407	1,383,545,579,408	1,383,545,579,409	1	1	400.0	400.0
0x03	1,383,545,579,407	1,383,545,579,408	1,383,545,579,409	1	1	400.0	400.0
0x03	1,383,545,579,407	1,383,545,579,408	1,383,545,579,409	1	1	400.0	400.0
0x03	1,383,545,579,407	1,383,545,579,408	1,383,545,579,409	1	1	400.0	400.0
0x03	1,383,545,579,407	1,383,545,579,408	1,383,545,579,409	1	1	400.0	400.0
0x03	1,383,545,579,407	1,383,545,579,409	1,383,545,579,410	2	1	1,400.0	400.0
0x03	1,383,545,579,407	1,383,545,579,408	1,383,545,579,409	1	1	400.0	400.0
0x03	1,383,545,579,407	1,383,545,579,409	1,383,545,579,410	2	1	1,400.0	400.0
0x03	1,383,545,579,407	1,383,545,579,408	1,383,545,579,409	1	1	400.0	400.0
0x03	1,383,545,579,407	1,383,545,579,408	1,383,545,579,409	1	1	400.0	400.0
0x03	1,383,545,579,408	1,383,545,579,409	1,383,545,579,410	1	1	400.0	400.0
0x03	1,383,545,579,408	1,383,545,579,410	1,383,545,579,411	2	1	1,400.0	400.0
0x03	1,383,545,579,408	1,383,545,579,409	1,383,545,579,410	1	1	400.0	400.0
0x03	1,383,545,579,408	1,383,545,579,409	1,383,545,579,410	1	1	400.0	400.0
0x03	1,383,545,579,408	1,383,545,579,410	1,383,545,579,411	2	1	1,400.0	400.0
0x03	1,383,545,579,408	1,383,545,579,409	1,383,545,579,410	1	1	400.0	400.0
0x03	1,383,545,579,408	1,383,545,579,410	1,383,545,579,411	2	1	1,400.0	400.0
				Average		750.0	400.0
				STD.		477.0	0.0

TABLE 22: APPLICATION AUTHENTICATION DATABASE AT NAP

APPLICATION AUTHENTICATION DATABASE AT NAP	
Application_UUID	String
Application_Name	String
Vendor_Name	String
Application_Version	Number
Application_specific_Public_Key	Big Integer

TABLE 23: A SAMPLE SESSION REQUEST PACKET

[0|1|1|66|39|-70|-11|-31|-1|-40|-1|-32|0|16|74|70|73|70|0|1|2|0|0|1|0|1|0|0|-1|-
37|0|67|0|8|6|6|7|6|5|8|7|7|7|9|9|8|10|12|20|13|12|11|11|12|25|18|19|15|20|29|26|31|30|29|26|28|28|32|36|46|
39|32|34|44|35|28|28|40|55|41|44|48|49|52|52|52|31|39|57|61|56|50|60|46|51|52|50|-1|-
37|0|67|1|9|9|9|12|11|12|24|13|13|24|50|33|28|33|50|50|50|50|50|50|50|50|50|50|50|50|50|50|50|50|50|-1|-
50|-1|-
64|0|17|8|0|37|0|37|3|1|34|0|2|17|1|3|17|1|-1|-
60|0|31|0|0|1|5|1|1|1|1|1|0|0|0|0|0|0|0|1|2|3|4|5|6|7|8|9|10|11|-1|-60|0|-
75|16|0|2|1|3|3|2|4|3|5|5|4|4|0|0|1|125|1|2|3|0|4|17|5|18|33|49|65|6|19|81|97|7|34|113|20|50|-127|-111|-
95|8|35|66|-79|-63|21|82|-47|-16|36|51|98|114|-
126|9|10|22|23|24|25|26|37|38|39|40|41|42|52|53|54|55|56|57|58|67|68|69|70|71|72|73|74|83|84|85|86|87|88|89|
90|99|100|101|102|103|104|105|106|115|116|117|118|119|120|121|122|-125|-124|-123|-122|-121|-120|-119|-118|-
110|-109|-108|-107|-106|-105|-104|-103|-102|-94|-93|-92|-91|-90|-89|-88|-87|-86|-78|-77|-76|-75|-74|-73|-72|-71|-70|-
62|-61|-60|-59|-58|-57|-56|-55|-54|-46|-45|-44|-43|-42|-41|-40|-39|-38|-31|-30|-29|-28|-27|-26|-25|-24|-23|-22|-15|-
14|-13|-12|-11|-10|-9|-8|-7|-6|-1|-60|0|31|1|0|3|1|1|1|1|1|1|1|1|1|0|0|0|0|0|1|2|3|4|5|6|7|8|9|10|11|-1|-60|0|-
75|17|0|2|1|2|4|4|3|4|7|5|4|4|0|1|2|119|0|1|2|3|17|4|5|33|49|6|18|65|81|7|97|113|19|34|50|-127|8|20|66|-111|-
95|-79|-63|9|35|51|82|-16|21|98|114|-47|10|22|36|52|-31|37|-
15|23|24|25|26|38|39|40|41|42|53|54|55|56|57|58|67|68|69|70|71|72|73|74|83|84|85|86|87|88|89|90|99|100|101|1
02|103|104|105|106|115|116|117|118|119|120|121|122|-126|-125|-124|-123|-122|-121|-120|-119|-118|-110|-109|-108|-
107|-106|-105|-104|-103|-102|-94|-93|-92|-91|-90|-89|-88|-87|-86|-78|-77|-76|-75|-74|-73|-72|-71|-70|-62|-61|-60|-59|-
58|-57|-56|-55|-54|-46|-45|-44|-43|-42|-41|-40|-39|-38|-30|-29|-28|-27|-26|-25|-24|-23|-22|-14|-13|-12|-11|-10|-9|-8|-
7|-6|-1|-38|0|12|3|1|0|2|17|3|17|0|63|0|-11|-113|22|-8|-76|-8|92|-62|76|22|-51|11|65|36|-14|-51|115|60|-111|-
84|106|-113|20|96|97|34|-111|-104|-106|-103|123|113|-118|-58|127|-118|16|90|90|67|115|125|-89|102|57|37|113|-
70|-54|115|54|98|91|68|-71|14|-86|-56|-114|114|36|80|114|-95|87|-110|-52|-68|103|75|-58|-38|5|-10|-80|108|-27|-
79|-74|75|-110|-118|-16|75|28|109|-60|-118|82|71|-120|-110|86|88|37|86|0|-58|27|-79|27|120|-36|78|43|-121|-
113|85|-78|-45|70|-97|113|44|-82|-6|13|-44|-16|-50|117|31|-74|121|112|111|-115|32|-108|-88|-115|45|85|73|-
116|90|44|106|-96|2|-59|-39|70|27|120|-113|-33|-64|-31|48|-43|-88|69|-72|115|75|91|-39|-21|-27|-89|123|109|-34|-
37|110|-52|-91|38|-98|-26|-4|-97|21|36|125|103|-5|34|-37|65|-51|-14|75|52|115|-57|45|-14|57|-113|102|-46|48|-
80|9|93|-40|-122|25|10|-65|41|12|50|66|59|45|-69|-97|-120|-78|69|-86|91|-39|13|58|-38|-35|-18|-89|-114|-38|-
38|61|66|-26|104|-90|121|26|40|100|42|-56|-112|72|16|-113|61|20|-27|-70|-26|-72|-85|-115|23|81|105|-84|108|-37|-
62|-9|70|-115|-31|-74|-35|-66|9|101|-114|-49|-52|9|20|-118|37|-114|88|34|-113|99|52|72|10|111|37|87|41|-57|-
105|18|-84|-112|92|91|57|-45|46|112|-22|-9|54|102|-5|79|-72|-1|0|64|88|100|-106|-34|-35|67|-7|123|-95|127|-
77|48|16|-63|-72|18|-88|-84|36|0|-97|45|119|-10|-68|-65|8|-46|106|29|31|-38|-7|-89|-69|-45|71|-93|-24|-101|-13|39|-
98|71|-81|-24|-70|-113|-10|-58|-125|-89|106|126|87|-109|-10|-53|104|-18|60|-67|-37|-74|111|80|-40|-50|6|113|-98|-
72|-94|-115|22|-51|52|-19|7|78|-79|-114|57|-93|-114|-38|-38|56|85|39|42|100|80|-86|0|12|87|-27|45|-57|56|-
29|61|40|-81|-105|-85|-53|-49|46|77|-81|-95|-78|-40|-26|62|32|-63|-89|-35|37|-110|77|19|-1|0|105|-37|44|-105|-
106|50|-86|-82|3|3|28|91|73|-5|-8|45|60|103|17|-2|-16|-108|5|14|-16|-128|-14|-80|105|-6|69|-107|-102|11|-
123|75|49|30|-95|36|-33|100|-65|-72|18|19|103|106|-114|-110|-89|-103|20|89|-100|-84|83|50|-7|70|73|0|11|-76|-
79|9|34|86|-1|0|-60|-106|-71|47|111|29|-67|-116|-41|-8|-79|-72|-111|-84|-19|-19|-95|-106|73|-15|61|-86|-19|-3|-
28|82|-31|70|-3|-28|5|-28|-96|39|-96|-57|15|115|98|-77|38|-103|105|62|-103|48|-74|-77|-66|26|-115|-59|-85|8|45|-
29|-118|53|-126|-54|73|22|120|-110|36|89|27|-9|-51|24|98|16|40|98|92|-124|12|71|-45|101|-76|-36|80|-
80|78|86|78|-3|117|-46|-1|0|-81|-33|-47|-34|-24|-58|111|-34|52|-96|-45|82|77|66|93|83|82|-80|-71|75|-37|91|56|35|-
77|-114|-56|-49|11|36|-13|53|-28|-7|-124|-53|36|83|48|-110|77|-60|6|100|31|-21|-117|114|-30|89|121|-
3|50|13|43|82|-97|72|72|-30|-41|-11|45|62|-17|76|-73|-116|-23|15|-87|-88|121|-40|92|-52|-97|54|93|11|36|65|25|-
108|34|-128|48|25|-116|99|113|47|-70|-16|-108|3|80|-80|-74|-121|100|-9|18|

TABLE 24: A SAMPLE CHALLENGE PACKET

[illegible]

Table-25: A sample RESPONSE packet

65|0|0|1|66|39|-70|-9|103|0|0|4|-45|77|124|-29|-102|-73|37|76|-42|9|-31|-
60|31|81|21|37|-94|-94|75|-44|1|-25|38|-96|105|-49|-59|-67|-11|-13|-65|-
10|103|46|45|-13|-15|-75|36|96|119|21|25|36|-33|108|29|15|-121|42|115|93|-19|-56|-
79|-7|38|-43|-4|82|64|14|55|-65|40|-36|97|-92|-115|98|-85|54|120|-77|111|-120|-26|-
35|-128|-20|-104|-24|88|-7|53|-15|-14|-31|16|33|114|1|74|68|81|-24|-2|-27|-100|44|-
71|-87|6|-97|10|2|-23|63|-52|99|-58|-127|-85|63|112|81|-97|107|-37|-69|78|-32|-27|-
69|-120|-50|-14|33|93|

Table-26: A sample OSL Acknowledgement packet

97|0|0|1|66|39|-70|-9|-90|0|3|-95|66|0|69|-82|0|-70|107|-
27|31|1|103|82|97|46|113|-95|15|96|119|-17|65|15|-80|59|-62|-69|101|-44|72|-
112|56|88|111|-44|-50|-122|24|54|-47|30|-92|-59|28|-65|70|32|-99|-113|83|-66|-
16|72|60|-76|102|23|-83|-101|-48|55|-39|-54|127|-70|0|-98|25|11|-
105|36|28|13|-107|101|115|126|21|95|-96|-40|-114|-118|89|-107|-38|60|-111|-
23|-105|-56|25|69|93|126|-34|-124|-35|32|9|-14|8|3|-101|17|81|-48|-1|62|-
62|56|-121|100|-5|-41|63|6|-71|-31|-30|93|100|-8|-1|126|61|-96|95|-7|-18|92|-
77|0|-71|

Table-27: A sample Data Communication packet

-127|0|0|1|66|39|-70|-9|-75|0|44|28|-8|48|-13|125|-27|59|-20|52|-23|56|-
8|125|-46|125|-29|46|-86|60|-7|54|-17|57|-86|41|-27|125|-7|41|-21|47|-2|125|-
30|52|-7|125|-25|52|-7|46|-29|50|-28|-102|59|-16|-63|92|-42|70|-82|-
110|73|12|27|47|-26|32|25|-33|67|23|-40|-98|-105|77|-88|-53|-76|3|-85|-
23|69|-105|100|126|51|105|114|-117|-26|-13|-66|9|47|48|-25|-89|-74|39|-
121|70|17|19|91|5|-100|112|99|40|-79|113|111|-112|79|94|56|69|-12|0|-33|-
87|17|122|84|-59|59|-26|-40|-26|-20|-70|88|18|-89|78|64|62|-35|93|21|-16|-
64|20|-122|108|0|13|-27|-24|-123|1|-45|-78|7|-101|83|-100|84|-10|73|86|-
56|29|73|-18|-105|-22|11|-92|17|-122|-28|29|-88|81|-84|-38|-6|-71|-99|

TABLE 28: KEYS OF THE SERVER

PRIVATE KEY OF THE SERVER	
93632166035672942999869443652446366821128962009188675105500097928710583288	
72873411317162971107390855259434642629576847033880663274773999054952551786	
52628551505613731052702203877726203841202858511642288445521677453012215970	
04639006359294453490292923967036744914550406950360220408454895269365879988	
318545257739	
29793936104916666208695506018403596955732233299351826153929826543865762911	
07540810833698774729901107703743687342984811145529202617332758232631651051	
40941937267729047202267629159225221003739222323370640793147440581659632473	
64592709460504451856531560825720878594550313434435661149593117867720601743	
906685260225	
PUBLIC KEY OF THE SERVER	
93632166035672942999869443652446366821128962009188675105500097928710583288	
72873411317162971107390855259434642629576847033880663274773999054952551786	
52628551505613731052702203877726203841202858511642288445521677453012215970	
04639006359294453490292923967036744914550406950360220408454895269365879988	
318545257739	
65537	

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