A certificateless public key encryption based return routability protocol for next-generation IP mobility to enhance signalling security and reduce latency

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Abstract. IPv6 mobility is an IETF standard that has added roaming capabilities of mobile node (MN). It allows MNs to travel from one network to another without any distraction in communication service. MNs register their current location to home stations and correspondent hosts via a process known as *binding update*. In IPv6 mobility, return routability protocol (RRP) is a standard procedure for updating the current location of MNs through binding update message to their communicants. However, RRP has several security threats and issues. Subsequently, RRP was integrated with identity-based encryption for improvement of security. Nevertheless, it suffers from some limitations such as inherent key escrow problem, lack of key revocation, high computational load and latency while providing security. Hence, this paper proposes a novel approach called optimised RRP using certificateless public key encryption to address these issues. The proposed protocol is simulated and validated using Automated Validation of Internet Security Protocols and Applications (AVISPA) – a model checker. Finally, the simulation and numerical results illustrate the extent to which the proposed protocol surpasses the existing method in terms of enhanced security and significant reduction in communication payload with minimised latency.

Keywords. Binding update; confidentiality; authentication; return routability and mutual authentication.

1. Prologue

Internet protocol (IP) is an internet layer protocol that helps in delivering packets from a source to a destination host based on the IP address accessible in the packet header. Mobile IP is a communication protocol that allows mobile users associated with one network to stay connected even while moving to a different network with a different IP address [1, 2]. IPv6 mobility, also known as Mobile IPv6 (MIPv6), allows the mobile node (MN) to remain connected to a correspondent node (CN) even when the MN moves from a home network to another network. The principal elements of MIPv6 include mobile node (MN), home agent (HA) and correspondent node (CN). In the environment of IPv6 mobility, the MN obtains a Home-of address (HoA) from its original location with an initial registration. Additionally, it acquires a temporary address known as Care-of address (CoA) when it moves to a foreign network [3]. The CoA is registered to HA by MN. When a datagram is sent from CN to MN, it will be passed to the MN's HA. In turn, HA checks if the MN is in the home or

foreign network [4]. It then forwards the datagram to HoA of MN when it is in the home network and to CoA when it is in the foreign network.

Over the years, a number of BU schemes [5–8] were proposed. The base scheme known as *Return Routability Protocol* (RRP) is a binding update procedure that allows a node to confirm the presence of another node to which the packet is sent [9]. In order to overcome the various security threats faced by RRP, Return Routability using Identity-Based Encryption (RR-IBE) was suggested [10]. In RR-IBE that uses public key cryptography, private key is obtained from a trusted third party called Private Key Generator (PKG). However, this approach introduces the inherent key escrow problem and lack of key revocation [11, 12]. To overcome the disadvantages of RR-IBE, the current paper proposes an improved RRP that uses Certificate Less-Public Key Encryption (CL-PKE) [13].

The rest of the paper is organised as follows: Section 2 briefly explains the related works. Section 3 presents a brief review of the preliminaries required for the proposed protocol. Section 4 presents the security analysis of the proposed protocol. Section 5 verifies the security properties of the proposed protocol by formal analysis using AVISPA.

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Section 6 discusses the performance of our protocol with existing protocols in terms of communication payload and latency of BU.

2. Related works

2.1 Return routability protocol

The RRP mechanism sends BU messages between the mobile and correspondent host as shown in figure 1. It consists of the following messages: Home-of Initiation (HoTI), Care-of Test Initiation (CoTI), Home-of Test (HoT), and Care-of Test (CoT). Here, the MN sends HoTI and CoTI to CN in two modes: directly and through home agent. The communication link MN-HA is secured through IP security (IPSec) tunnelling. Then, CN receives the HoTI from the HA and the CoTI message from the MN. In turn, the CN sends HoT and CoT messages to MN by two methods: it sends the message directly or via base station. The RRP culminates the procedure when MN receives both the messages. However, the traditional RRP suffers from various security attacks such as replay, man-in-the-middle, reflection and amplification attacks. Hence, it is necessary to enhance the RRP to surmount these issues.

2.2 Return routability protocol with identity-based encryption

Identity-based encryption (IBE) is incorporated with RRP. This approach employs a trusted third party called the Private Key Generator (PKG). The PKG maintains a private key for a correspondent host. The RR-IBE provides authentication, confidentiality, integrity and attack prevention. Though RR-IBE has advantages, the use of PKG to generate the private key introduces an inherent key escrow problem. The PKG can falsify an entity's signature in an

identity-based signature method, thus the RR-IBE protocol cannot offer true non-repudiation. In addition, IBE in its most basic form lacks in key revocation.

3. Proposed protocol

The proposed protocol with CLPKE uses a trusted third party known as Key Generation Centre (KGC). In contrast to the PKG in RR-IBE, the KGC does not have access to private key of the entities. Instead, the KGC supplies the entity with a partial private key. The proposed protocol is based on the following assumptions:

- The MN first registers with HA and CN to acquire the public keys.
- There exists a secure IPSec tunnel between MN and HA.
- The path between CN and KGC is secured because KGC authenticates each of the registered communicants.

3.1 Phases of key generation

Key generation of the proposed approach consists of five phases. Here, let a security parameter k be given as an input to the *setup* phase [12].

1. *Preliminary setup*: The *setup* phase is executed by the KGC and the output is distributed to the MN, CN and HA. It operates as follows,

- Run a Bilinear Diffie-Hellman parameter generator algorithm with input k and generate the output as (G_1, G_2, e) , where e is a bilinear map such that $e: G_1 \times G_1 \rightarrow G_2$. Here, G_1 and G_2 denote an additive group and a multiplicative group of some prime order q respectively.
- Select an arbitrary generator P of group G_1 .
- Choose a master key s at random from Z_q^* and $P_0 = s.P$

The output generated from the *setup* phase is $(G_1, G_2, e, n, P, P_0, H_1, H_2, H_3, H_4)$, called as *params*, where n is the length of the plaintext; H_1, H_2, H_3 , and H_4 are hash functions and defined as follows,

$$\begin{aligned} H_1 &: \{0, 1\}^* \rightarrow G_1^* \\ H_2 &: G_2 \rightarrow \{0, 1\}^n \\ H_3 &: \{0, 1\}^n \times \{0, 1\}^n \rightarrow Z_q^* \\ H_4 &: \{0, 1\}^n \rightarrow \{0, 1\}^n. \end{aligned}$$

2. *Extraction of partial private key*: The KGC runs this phase to produce a partial private key of CN. It uses an identifier of CN (ID_{CN}) as input and generates the partial private key as follows,

Figure 1. Return routability protocol.

$$D_{CN} = s.H_1(ID_{CN})$$

3. *Generation of secret value:* This phase is executed by MN, CN and HA separately that takes params and their respective IDs (i.e., ID_{MN} , ID_{CN} and ID_{HA}) as inputs. The entities select secret values at random and gives output X_{MN} , X_{CN} , X_{HA} for MN, CN and HA, respectively.
4. *Generation of private key:* The CN generates the private key R_{CN} using the params, secret value X_{CN} and partial private key D_{CN} obtained from KGC. It is computed as follows:

$$R_{CN} = X_{CN}.D_{CN}$$

5. *Generation of public key:* This phase is run by CN. The inputs are params and its respective secret value X_{CN} . It computes the public key of CN, $P_{CN} = (A_{CN}, B_{CN})$, where $A_{CN} = X_{CN}P$ and $B_{CN} = X_{CN}P_0$.

3.2 Encryption and decryption

This section discusses the encryption and decryption.

Encryption: To encrypt a message $M \in \{0, 1\}^n$ by any entity, say CN with ID_{CN} and its public key P_{CN} , the following steps are performed:

- Check if $A_{CN}, B_{CN} \in G_1^*$ and $e(A_{CN}, P_0) = e(B_{CN}, P)$.
- Let $Q_{CN} = H_1(ID_{CN}) \in G_1^*$
- Select a value σ at random such that $\sigma \in \{0, 1\}^n$.
- Let $r = H_3(\sigma, M)$.
- Compute and output the ciphertext $C = (rP, \text{XOR}(\sigma, H_2(e(Q_{CN}, B_{CN})r)), \text{XOR}(M, H_4(\sigma)))$ such that $C = G_1 \times \{0, 1\}^n$

Decryption: Decryption of C can be done by CN using its private key R_{CN} as follows,

- Compute $\text{XOR}(\text{XOR}(\sigma, H_2(e(Q_{CN}, B_{CN})r)), H_2(e(R_{CN}, rP))) = \sigma$.
- Compute $\text{XOR}(\text{XOR}(M, H_4(\sigma)), H_4(\sigma)) = M$.
- Set $r = H_3(\sigma, M)$.
- Output M as the decryption of C . When C is a valid ciphertext of M using P_{CN} and ID_{CN} , then deciphering of C will result in an output $M' = M$.

3.3 Proposed protocol description

The pictorial representation of the proposed protocol is shown in figure 2.

Table 1 shows the notations used in the proposed protocol. The intricacies of the proposed message flows are as follows:

Initially, the MN sends the HOTI message to CN through the HA using IPSec tunnel mode. The message M1 contains the source addresses (MN_{COA} and MN_{HOA})

of the MN and the destination address of the HA (MN_{HAA}).

Here, M1 includes message with the old address of the MN (MN_{OldCOA}) to inform the HA or CN of the MN's preceding location before it moves to another network with MN_{COA} . Consequently, if a packet is sent from the CN to the existing MN_{COA} , the CN can know how to send this message to the present MN_{COA} . Both M1 and M1' contain a nonce or random number (N_0). On receiving both M1 and M1', the CN compares both the messages. If N_0 is same in both, then CN sends a partial private key request to the KGC. In the HOTI, HOTI', COTI and BU messages of MN, the random numbers are encrypted using certificateless public key encryption. This encryption is done using the public key of CN (P_{CN}) as mentioned in the previous section. The message flows of the proposed protocol are shown in figure 3 and the details are as follows,

Home-of Test Init:

$$MN \rightarrow HA : M1$$

where $M1 = MN_{HOA}, CN_{Addr}, MN_{OldCOA}, \{N_0, MN_{HOA}, MN_{COA}, P, P_0\}CLPKE_{P_{CN}}$

$$(HOTI')HA \rightarrow CN: M1'$$

where $M1' = MN_{HOA}, CN_{Addr}, MN_{OldCOA}, \{N_0, MN_{HOA}, MN_{COA}, P, P_0\}CLPKE_{P_{CN}}$

Care-of Test Init:

$$(COTI) MN \rightarrow CN : M2$$

where $M2 = ID_{MN}, MN_{OldCOA}, \{N_0, MN_{COA}, P, P_0\}CLPKE_{P_{CN}}$

Partial private key request:

$$(PPKReq) CN \rightarrow KGC : M3$$

where $M3 = CN_{Addr}, H_1(ID_{CN}), D_{reqCN}$

Authentication of CN and partial private key response:

$$(PPKRes) KGC \rightarrow CN : M4$$

where $M4 = D_{resCN}, H_2(CN_{Addr}), D_{CN}$

Authentication of MN:

$$(AU)CN \rightarrow MN : M5$$

where $M5 = CN_{Addr}, CN_{COA}, \text{XOR}(N_0, N_1)$

Binding update:

$$(BU)MN \rightarrow CN: M6$$

where $M6 = BU, CN_{Addr}, ID_{MN}, \{N_1, MN_{COA}, H_3[N_1]\}-CLPKE_{P_{CN}}$

Binding Acknowledgment:

$$(BA)CN \rightarrow MN: M7$$

where $M7 = BA, CN_{CNA}, CN_{COA}, \text{XOR}(N_0, N_1)$

Figure 2. Proposed protocol architecture.

Table 1. Notations used in proposed protocol.

Symbol	Description
$A \rightarrow B : M$	A sends the message M to B
{Set of fields}	Encryption of set of fields
$CLPKE_{P_e}$	CLPKE with the key P_e
$Dreq_{CN}$	Partial private key request
$Dres_{CN}$	Partial private key response
MN_{COA} and MN_{HOA}	MN's care-of address and home of address
MN_{OldCOA}	MN's old care-of address
MN_{HAA}	MN's home agent address
CN_{Addr}	Address of the correspondent node
N_0, N_1	Nonces
BU, BA	Bit patterns indicating binding update and acknowledgement
P_{KCN}	Public key of CN

4. Security analysis

In this section, security attributes such as authentication, confidentiality, data integrity, inherent key escrow and attack prevention are discussed.

4.1 Data authentication

In the proposed protocol, authentication is provided between all the correspondent pairs. Here, an encrypted nonce N_0 using CLPKE is sent in the messages M1, M1' and M2. This nonce sent from MN to CN can be used for authentication from messages M5 to M7. The CN then authenticates MN by generating N_1 and subsequently performs XOR with N_0 and sends it to MN. Further, MN authenticates CN by sending N_1 to CN. In the proposed

protocol, KGC also provides authentication for its communicants using hash functions.

4.2 Data confidentiality and integrity

The public key P_{CN} is used for enciphering in M1, M2 and M6. The secret value X_{CN} used in P_{CN} is generated using the identity of CN (ID_{CN}) and is known only by CN. M5 depends on the nonce N_0 from the prior M1' and M2, where N_0 is identified by the mobile and correspondent node. M5 performs XOR with N_0 and N_1 and, hence, the preliminary message for the scheme uses secure communication through tunnelling. All enciphered packets require a private key for deciphering, making it hard for an impostor to take out any field from the packets. In RR-IBE when the PKG is compromised and the private key is known, the intruder can decrypt and view the messages, whereas in the proposed protocol when the partial private key is compromised, the intruder cannot decrypt the messages. Here, the MN sends two messages (M1 and M2) to CN. The intruder can seize the messages, but cannot decipher or modify the data since these messages are enciphered with the public key of CN (P_{CN}). The CN can explore for any modification by comparing M1' with M2. In addition, the impostor cannot generate a fake message since he only recognises the address of CN. Consequently, any alteration to the exchanged packet cannot be possible unless an opponent knows the secret value of CN.

4.3 Preventing inherent key escrow

In the RR-IBE protocol, the use of PKG to generate the private key introduces the inherent key escrow problem because if the PKG is compromised with an adversary, then he can decrypt the ciphertext using the private key. To address this issue, the proposed protocol involves KGC to generate only the partial private key. The KGC then distributes the partial private key to CN (it can generate the private key as discussed in section 3.1). Thus, the proposed protocol prevents the key escrow problem and the attacker from acquiring the private key of CN.

4.4 Man-in-the-middle attack prevention

An opponent might lay down himself as the man-in-the-middle (MITM) between a legitimate MN and the CN by sending false BUs. However, the proposed protocol prevents MITM attack without revealing any information to the opponent. If he alters the address of the message, the correspondent user can detect it easily since the message contains the original address of MN. In addition, the CN compares messages M1' and M2. If it finds that their contents are not equivalent, it rejects the message M2. Subsequently, it does not send a message requesting a partial

Figure 3. Message sequence diagram of the proposed protocol.

private key from KGC. If an intruder receives M5 from CN, it alters its address, and sends the false address to the mobile user. However, the MN receives M5 and compares it with the message M2 to notice any changes that occurred in M5. As a result, the MN can identify the opponent and prevent the message M6.

4.5 Replay attack prevention

The attacker can monitor the communication channel, record the current run of the message, and replay it later. Suppose the intruder captures M1 from HA and sends it to CN without altering its fields. Here in the proposed protocol, CN compares M2 with M1'. If M1' and M2 are found equivalent, it obtains the partial private key from KGC to generate the private key R_{CN} to decrypt the message.

If the attacker sends both M1' and M2 to the CN, it receives the partial private key from the KGC and acquires N_0 , which is recognised through the legitimate MN and CN. The CN sends a message M5 to the intruder that contains the XOR value of N_0 with a fresh random number N_1 . Here, the possible replay is prevented since the attacker does not know N_0 .

4.6 Amplification attack prevention

Generating more than one message from an original message and sending to all the nodes is called an *amplification*

attack. Here, the attacker sends a message from CN to MN via HA to send more number of messages to other nodes. It is prevented in the proposed protocol since no messages or data are sent from CN to the home network in our protocol. In addition, KGC verifies the authentication of all the communicants. Table 2 lists the security analysis of the proposed protocol with existing protocols.

5. Formal analysis using AVISPA

In this section, a formal analysis of the proposed protocol is presented using Automated Validation of Internet Security Protocols and Applications (AVISPA) to validate the security properties [14, 15]. AVISPA is basically a security tool that provides High-Level Protocol Specification Language (HLPSP) for describing the properties of security protocols. The written HLPSP is then translated into Intermediate Format (IF). Subsequently, the translated IF is fed into the following back-ends of AVISPA for automatic analysis to detect the attacks.

1. On-the-fly Model-Checker (OFMC)
2. Constraint – Logic-based Attack Searcher (CL-AtSe)
3. SAT-based Model-Checker (SATMC)
4. Tree Automata based on Automatic Approximations for the Analysis of Security Protocols (TA4SP).

In AVISPA, the entities of the model are defined by a role. The proposed protocol is specified with the role definition of the entities for MN, HA and CN. The role definition of

Table 2. Security analysis.

	MN-HA			MN-CN		
	RR	IBE	Proposed	RR	IBE	Proposed
Authentication	Yes	No	Yes	No	Yes	Yes
Data confidentiality	Yes	Yes	Yes	No	Yes	Yes
Data integrity	Yes	Yes	Yes	No	No	Yes
Preventing inherent key escrow	No	No	Yes	No	No	Yes
MITM attack prevention	No	Yes	Yes	No	No	Yes
Replay attack prevention	No	Yes	Yes	No	Yes	Yes
Amplification attack prevention	No	Yes	Yes	No	Yes	Yes

an entity contains the variables and set of transitions. The sample role definition of MN for the proposed protocol is shown in figure 4. Once the HLPSP specification has been debugged, it is translated into IF. Next, the back-ends of AVISPA run with IF file to identify the attacks. Figure 5 shows the simulation results of AVISPA for the RR-IBE and the proposed protocol. These results show that no revealed attacks are found and security goals are attained for the proposed protocol.

```

role mn(MN, HA, CN, KGC: agent,
  Kcn: public_key,
  Hashv: hash_func,
  SND, RCV, SND1, RCV1: channel(dy))
  played_by MN def=
    local CoA, HoA, OldCoA, CNA, RPP, Dcn, N0, BA, BU, DcnReq,
    N1, N2: text, State: nat

    init State = 0
    transition
      0.State = 0 ∧ RCV(start) =>
        State := 6 ∧ N0' := new () ∧ CoA' := new () ∧ OldCoA' := new () ∧ CNA' := new (
        ) ∧ HoA' := new () ∧ Msglen' := new () ∧ Type' := new () ∧ SND (CoA', HoA',
        OldCoA', CNA', {N0', HoA', CoA', Msglen', Type'}) _Kcn) ∧ SND1
        (CoA', CNA, OldCoA', {N0', HoA', CoA', Msglen', Type'}) _Kcn) ∧ secret
        (N0', n0, {MN, HA, CN})

        6.State = 6 ∧ RCV(CNA', CoA'.xor(N0, N1')) =>
        State := 8 ∧ BU' := new () ∧ SND(CoA', CNA', {N1', BU'}) _Kcn) /request(MN, C
        N, mn_cn_n0, N0) /witness(MN, CN, mn_cn_n1, N1') /
        secret(BU', bu, {MN, CN})

        8.State = 8 ∧ RCV(CNA, CoA.BA') =>
        State := 10 ∧ SND (CNA, CoA)

```

Figure 4. Role of a mobile node in AVISPA.

6. Performance evaluation

In this section, performance analysis of the proposed scheme with the other related works are presented in terms of communication payload and latency of the binding update.

6.1 Message size

The total size (in bytes) required for all messages is obtained during the run of the protocol. Here, the total message size computed for RRP, RR-IBE and the proposed protocol are 396, 1572 and 992 bytes, respectively. The size of messages can be calculated using the individual components of the protocol such as HOTI, COTI, BU and BA. For example, the message size of HOTI of the proposed protocol is computed as follows:

Message size of HOTI = $5 * 128 + 1024 = 1664$ bits. Total no of bytes required for each step of the proposed protocol = HOTI + HOTI' + COTI + PPKReq + PPKRes + AU + BU + BA = $1664 + 1408 + 408 + 320 + 512 + 320 + 1280 + 256 = 7936$ bits = 992 bytes.

By observing the total computations as shown in table 3, the communication payload of the proposed protocol is less than RR-IBE and is higher than RRP because the security provided in RRP is less when compared to the proposed protocol.

6.2 Latency of binding update

Latency is the measure of the time consumed for a message to move from source to destination. The BU latency of the proposed protocol can be calculated using the system parameters (shown in table 4) obtained from the existing works [16–18]. The transmission time of any message can be computed as follows:

$$\text{Transmission time} = \text{Size of data/Bit rate.}$$

The BU latency for the proposed protocol can be calculated as follows:

Total BU latency = Time required at source for sending messages + Time required at intermediate nodes + Time required at destination for processing the messages. The computation of the latency is as follows:

$$\begin{aligned} \text{Latency between MN and HA} &= 3.332 + 2.768 \\ &+ 0.5 = 6.664 \text{ ms} \end{aligned}$$

$$\begin{aligned} \text{Latency between MN and CN} &= 7.34 + 9.628 + 6.288 \\ &= 23.256 \text{ ms} \end{aligned}$$

6.3 Communication payload

The communication payload includes the length of the header and the message content. Figures 6 and 7 show the

<pre> % OFMC % Version of 2006/02/13 SUMMARY UNSAFE DETAILS ATTACK_FOUND PROTOCOL /home/avispa/web-interface-computation/./tempdir/workfile9ePaQg.if GOAL secrecy_of_pvtrep BACKEND OFMC COMMENTS STATISTICS parseTime: 0.00s searchTime: 0.04s visitedNodes: 0 nodes depth: 0 plies ATTACK TRACE i -> (pkg1,3): x246.x247.x248 (pkg1,3) -> i: x247.x246.Rep(1).SIDCN(1) i -> (i,17): Rep(1) i -> (i,17): Rep(1) </pre>	<pre> SUMMARY UNSAFE DETAILS ATTACK_FOUND TYPED_MODEL PROTOCOL /home/avispa/web-interface-computation/./tempdir/workfile9ePaQg.if GOAL Secrecy attack on (n17(Rep)) BACKEND CL-AtSe STATISTICS Analysed : 1 states Reachable : 1 states Translation: 0.04 seconds Computation: 0.00 seconds </pre>
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(a)

<pre> OFMC RESULT: SUMMARY SAFE DETAILS BOUNDED_NUMBER_OF_SESSIONS PROTOCOL /home/avispa/web-interface- computation/./tempdir/workfilebpxo21.if GOAL as_specified BACKEND OFMC COMMENTS STATISTICS parseTime: 0.00s searchTime: 0.16s visitedNodes: 29 nodes depth: 8 plies </pre>	<pre> CL-AtSe RESULT: SUMMARY SAFE DETAILS BOUNDED_NUMBER_OF_SESSIONS TYPED_MODEL PROTOCOL /home/avispa/web-interface- computation/./tempdir/workfile2e3rgY.if GOAL As Specified BACKEND CL-AtSe STATISTICS Analysed : 4 states Reachable : 4 states Translation: 0.04 seconds Computation: 0.00 seconds </pre>
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(b)

Figure 5. (a) OFMC and CL-AtSe results of RR-IBE. (b) OFMC and CL-AtSe results of proposed protocol.

comparison between the proposed protocol and the existing protocols in terms of communication payload between MN and CN through HA and directly between MN and CN.

From the observations of both cases, it is seen that the proposed protocol provides less cost for communication payload of the BU messages when compared to RR-IBE. It is because of the following reasons in the proposed protocol: (i) the requirement for a pair of keys to get the CN's

private key is eliminated as the CN receives only the partial private key from the KGC and not the complete private key; (ii) The contents of the messages are reduced; and (iii) light-weight encryption is done using CLPKE, which does not require any pairing operations. However, the proposed protocol incurs higher cost than RRP in case of communication payload between MN and CN but it provides better security.

Table 3. Size of messages.

Protocol	Message size for single BU (in bytes)			Total
	MN-HA-CN	MN-CN	CN-key generator	
RRP	192	204	-	396
RR-IBE	672	700	200	1572
Proposed	384	408	104	992

Table 4. System parameters.

Processing time in HA,CN and MN	0.5 ms
Propagation time in wireless links	2 ms
Bit rate in wireless links	2 Mbps
Propagation time in wired links	0.5 ms
Bit rate in wired links	100 Mbps
SHA operation on MN	0.019111 ms

Figure 6. Communication payload between MN and CN through HA (in bytes). **Figure 7.** Communication payload between MN and CN (in bytes).

Figure 8 shows comparison results of the proposed protocol with the existing protocols in terms of the processing time (in ms).

(a) **(b)** **(c)****Figure 8.** (a) Processing time at source MN. (b) Processing time at intermediate between MN and HA. (c) Processing time at destination HA.

Figure 8a shows that the time taken by the proposed protocol at source MN is less than that of RR-IBE. Here, the processing time at source depends on the transmission time of the messages P1 and M1 for RR-IBE and RR, respectively. Similarly, the time taken (shown in figure 8b) at intermediate for the proposed protocol is less than RR-IBE. Figure 8c illustrates that the time taken at destination HA for the proposed protocol. Subsequently, both transmission time and computational time are also taken into account for computing the total latency.

Figure 9. Computational latency (in ms) between MN and CN: (a) at MN, (b) between MN and CN and (c) at CN.

Figure 9 demonstrates the comparison analysis of total latency at MN between the intermediate pair MN-CN and at HA in the proposed and existing works. From figure 9a and b, it is observed that the latency at intermediate and source for the proposed protocol is more than RRP but the latency at destination by the proposed protocol is less than RRP. But it provides enhanced security when compared to RRP. Evidently, the performance of the proposed protocol stands out among the other protocols because the proposed protocol uses few messages from MN to HA or to CN along with significant reduction in computation time for cryptographic operations.

7. Conclusion

In this paper, an enhanced Return Routability Protocol is proposed using CLPKE in mobility of IPv6. It provides authentication, confidentiality, integrity and possible attack preventions. In addition, the formal validation is verified

using AVISPA for attack trace. No revealed attacks such as MITM, replay, amplification and false BU are found from the results of back-ends of AVISPA when compared to RR-IBE. The performance evaluation of the proposed protocol illustrates that the new approach reduces the latency when compared to the existing RRP.

References

- [1] Al-Surmi I, Othman M and Ali B M 2012 Mobility management for IP-based next generation mobile networks: review, challenge and perspective. *J. Netw. Comput. Appl.* 35: 295–315
- [2] Mathi S K and Valarmathi M L 2015 A secure and efficient binding update scheme with decentralized design for next generation IP mobility. In: *Artificial Intelligence and Evolutionary Algorithms in Engineering Systems*, Springer, India, pp. 423–431

- [3] Modares H, Moravejosharieh A, Lloret J and Salleh R 2014 A survey of secure protocols in mobile IPv6. *J. Netw. Comput. Appl.* 39: 351–368
- [4] Mathi S K and Valarmathi M L 2013 An efficacious and secure registration for internet protocol mobility. *Defence Sci. J.* 63(5): 502–507
- [5] Arkko J, Vogt C and Haddad W 2007 *Enhanced Route Optimization for Mobile IPv6*, RFC4866
- [6] Han Y H and Hwang S H 2006 Care-of address provisioning for efficient IPv6 mobility support. *Comput. Commun.* 29(9): 1422–1432
- [7] Ren K, Lou W, Zeng K, Bao F, Zhou J and Deng R H 2006 Routing optimization security in mobile IPv6. *Comput. Netw. Elsevier* 50(13): 2401–2419
- [8] Vogt C, Bless R, Doll M and Kuefner T 2005 Early binding updates for mobile IPv6. In: *Proceedings of International Conference on Wireless Communications and Networking*. 3, pp. 1440–1445
- [9] Yoon H S, Kim R H, Hong S B and Youm H Y 2006 PAK-based binding update method for mobile IPv6 route optimization. In: *International Conference on Hybrid Information Technology*, 2, pp. 617–623
- [10] Alsalihi W A A and Alsayfi M S S 2013 Integrating identity-based encryption in the return routability protocol to enhance signal security in mobile IPv6. *Wireless Personal Commun.* 68(3): 655–669
- [11] Barreto P S, Kim Y, Lynn B and Scott M 2002 Efficient algorithms for pairing-based cryptosystems. In: *Proceedings of International Conference on Advances in Cryptology*, Springer, Berlin Heidelberg, pp. 354–369
- [12] Wang F and Zhang Y 2008 A new provably secure authentication and key agreement mechanism for SIP using certificateless public-key cryptography. *Comput. Commun.* 31(10): 2142–2149
- [13] Zhang Z, Wong D S, Xu J and Feng D 2006 Certificateless public-key signature: security model and efficient construction. In: *Proceedings of International Conference on Applied Cryptography and Network Security*. Springer, Berlin Heidelberg, pp. 293–308
- [14] AVISPA Team, 2013, AVISPA v1.1 user manual
- [15] Pura M, Patriciu V and Bica I 2009 Modeling and formal verification of implicit on-demand secure ad hoc routing protocols in HLPSP and AVISPA. *Int. J. Comput. Commun.* 2(3): 25–32
- [16] Argyroudis P G, Verma R, Tewari H and O'Mahony D 2004 Performance analysis of cryptographic protocols on handheld devices. In: *Proceedings of 3rd IEEE International Symposium on Network Computing and Applications*. pp. 169–174
- [17] Hess A and Shafer G 2002 Performance evaluation of AAA/Mobile IP Authentication. In: *Proceedings of 2nd International Symposium on Polish-German Teletraffic*, Gdansk, Poland
- [18] McNair J, Akyildiz I F and Bender M D 2000 An inter-system handoff technique for the IMT-2000 system. In: *Proceedings of International Computer and Communications*. 1: 208–216