Fostering a Secure Framework for National Research and Education Network

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Abstract

In the context of management of network services, wide-spread deployment and security problems requiring considerable human efforts and involvement, secure and distributed management mechanism become a central concern. Considering both National and International indicators, there is a big inadequacy on secured networks in the developing countries compared to other countries. This important problem will definitely affect the collaborative efforts in research and education networking in Africa. In order to see to the improvement towards emerging networks and collaboration in Africa, the paper proposes a framework not exploited through the collaborative research and educational network by malicious interference of the shared resources. The paper tends to bridge the gap of insufficient ICT infrastructures using minimal hardware that demonstrated it can be used for building higher level security protocols. In order to tolerate the failure and provide uninterrupted services to network components, the work examined the behaviour and fault tolerance of the proposed framework.

Keywords: Security, Education, Network, Research.

1. Introduction

This paper examines the security concerns and novel secured framework on deployment of National Research and Education Network (NREN) that is not exploited by malicious interference of shared resources. A Research and Education Network (REN) is an association of institutions that is focused on conducting research and educational instructions, with the aim of institutional collaboration for the purpose of maximising scarce resources, proffering solutions and improving infrastructure for the realisation of their organisational objectives [1]. The need for interconnectivity and interoperability does not imply that security issues should be compromised. Different user communities require different levels of security. Each network on which the national information infrastructure is built must have a number of security procedures implemented that will prevent unauthorized access to the network and the systems that comprise it [2]. Network technologies and services are now regarded as essential to support distributed research communities around the world. The development of these services however is in its infancy and the services will continue to evolve over the years in Africa.

The current network is characterized by its increasing distribution, its dynamic nature, and the complexity of its resources, due to the increasing requirement of different services [3]. Emphasis

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should be geared towards using frameworks that are developed on minimal hardware pushing some of the resources to be managed by fewer secure managed devices. Network management essentially involves monitoring and controlling the devices connected in a network by collecting and analyzing data from the devices [4]. The current trend is to deploy mobile agents to manage such large heterogeneous networks like NREN. Mobile agents are special software objects that have the unique ability to transport itself from one system in a network to another in the same network [5].

The approach is to automate the resource sharing and collaboration using secure mobile-agent resource transfer (SMART) protocol architecture for NREN simply called SMARTREN.

The paper explores the fostering of a security framework in NREN most especially situated in Africa. The novel method is to explore the use of proposed mobile agent protocol to create a robust NREN services. The remainder of the paper is organised into five sections. In the first section, we review related technology and REN, highlighting some issues of current approaches, particularly for existing NREN and national environments. In the second section, we summarise the research design employed for the study. In the third section, we provide a holistic security issues resolved in the study. The fourth section provides analysis and discussion of the key challenges faced by NREN new secure protocol. Fifth, conclusions are drawn, research limitations discussed, and future research directions proposed.

2. Related Network and NREN Technologies

It is critical to recognize that even in the present Internet, it has been possible to accommodate a remarkable amalgam of private enterprise, academic institutions, government and military facilities. Indeed, the very ability to accept such a diverse constituency turns on the increasing freedom of the so-called intermediate-level networks to accept an unrestricted set of users [6]. The Internet services do serve the public but extremely vulnerable to mass attacks, although the linkages between the Internet and the public make the system extremely accessible to a very wide variety of users. It will be important to keep in mind that, over time, an increasing number of institutional users will support local area networks and will want to gain access to NREN by that means.

Osazuwa [1], mentioned some NRENs that are presently sharing contents between members and provide their clients with research networks and Internet without necessarily providing a robust and secured networks using minimal hardware solutions. South African National Research Network (SANReN) provides connectivity to the world's research networks as well as commodity Internet access. TENET (Tertiary Education and Research Network of South Africa) is actively engaged in the construction of Access Networks connected to the SANReN network; provides Internet and information technology services, involving inter-alia, high-speed Internet access; inter-campus connectivity; ancillary operational functions in support of service delivery and the provision of other value-added services as may be needed from time to time in support of higher education and research in South Africa. National LambdaRail (NLR) advanced optical network infrastructure supports many of the world's most demanding scientific and network research projects. The Ghanaian Academic and Research (GARNET), is assisting to fulfil a very crucial need for research and education within Ghana by providing services aimed at fostering collaboration among research and educational institutions in the region as well as between them

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and peer institutions worldwide [7]. The Belgian Research and Education Network (BELNET) supplies Internet access with very high bandwidth to Belgian educational institutions, research centres and government services. Research and Education Network for Uganda (RENU) has been supporting teaching and learning, as well supporting advanced research within members and also nurtured local content networks. West and Central African Research and Education Network (WACREN) is charged with the responsibility for providing necessary assistance for the formation and sustenance of NRENs in the region. WACREN supports the development of properly structured campus networks such as NREN basic building blocks, and provides models and templates for NREN's in capacity building, organisational structure, financing access to bandwidth, business analysis and strategic plans [8].

The needs and benefits of these technologies do not imply that security issues should be compromised. Different NRENs require different levels of security but there must be a common ground in proffering platform independent secure protocol on which the national information infrastructure is built that will prevent unauthorized access to the network.

3. SMARTREN Architecture

The proposed flexible architecture, Secure Mobile Agent Resource Transfer (SMART) REN framework, is a hybrid model, which has features of secure mobile agent protocol as well as Simple Network Management Protocol (SNMP). The architecture forms a layer over the conventional SNMP based management that ensures the advantages of SNMP are not lost and also serves the purpose of managing legacy SNMP based systems. SMARTREN gives the Network Operating Centre (NOC) for stationed REN the flexibility of using SNMP model or SMARTREN depending on the resource sharing activity that is involved. This architecture has many advantages over the existing architectures. Some of the advantages are stated below:

- The repetitive request/response handshake is eliminated
- Reduces design risk by allowing decisions about the location of the code pushed towards the end of the development effort
- Resolves problems created by intermitted or unreliable network connections
- Real time notifications
- Parallel executions (or load balancing) where large computations are divided amongst processing resources which maintains minimal hardware usage.
- Offers an alternative to or complementing SNMP security in network management system

In the proposed architecture the REN station assumes responsibilities of their clients. All managed nodes are servers, which have mobile agent environment and respond to SNMP queries from mobile agents when they visit the context servers and manipulate data locally. When the client in the SMARTREN needs access to data in a network-connected device, it does not talk directly to the server over the network but dispatches a mobile agent to the server's machine. On arriving at the servers' machine, the mobile agent makes its request and return to the management station with the results. The architecture provides Java-compliant interfaces to network management services. Aglet Software Development Kit (ASDK) is the agent

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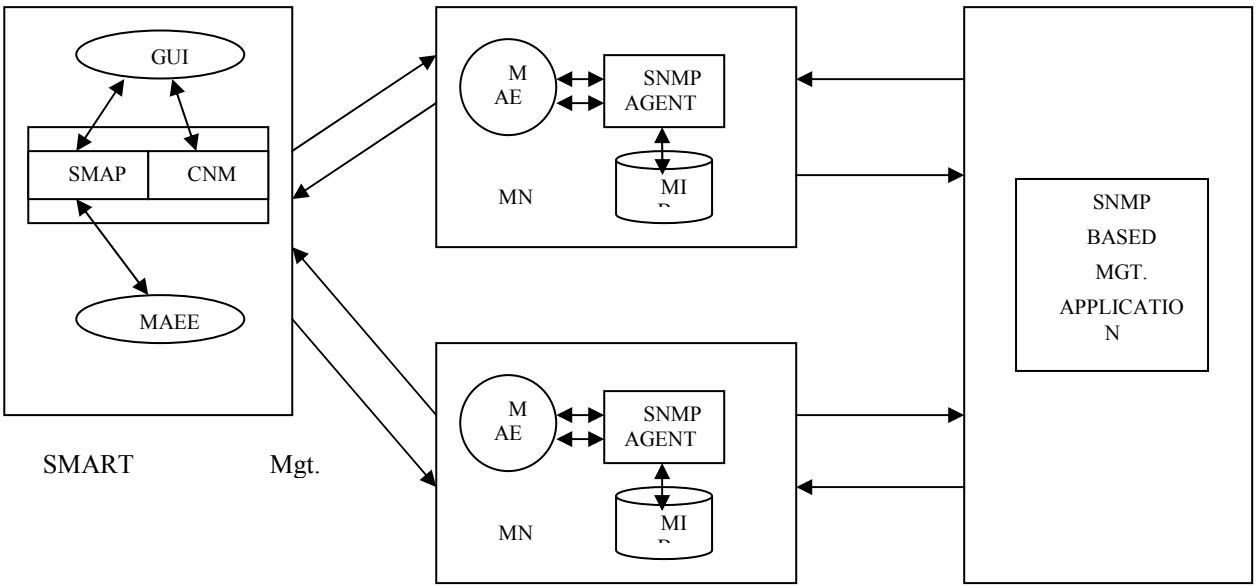
development environment to be used because of its modular structure, easy-to-use API for programming of mobile agents and excellent documentation. To interact with the SNMP agent, we use AdventNet SNMP [9]. It provides a set of Java tools for creating cross platform Java and Web-based SNMP network management applications. AdventNet provides a set of classes, which could be used to facilitate communication between managed device (a device with SNMP agent like Routers), and an SNMP manager or management application.

The SMARTREN architecture consists of the following major components:

- Management application (MAP)
- Mobile Agent Execution Environment (MAEE)
- Secure Mobile Agent Producer (SMAP)
- Mobile Agents (MA)
- Modified Multi-signcryption protocol (MMSP)

In the SMARTREN architecture, the mobile agents are provided with the list of nodes to be managed, SNMP statistics of interest and Health functions [10] defined by the user. The mobile agent development environment is the Aglet Software Developer Kit (ASDK), which provides a modular structure, easy-to-use API for programming of mobile agents and excellent documentation.

Figure 1 shows the hybrid model of SMARTREN and architecture for Resource Transfer using secure mobile agents. The REN administrator/manager is given the flexibility of deciding whether to use SNMPv3 or mobile agents. Every mobile agent enabled network device has to offer a mobile agent context server. The mobile agents hosted in the context servers communicate with the local SNMP agent via SNMP based management applications.



Network Devices Managed by Context Servers

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Figure 1: Hybrid SMARTREN Model

Keys:

GUI – Graphical user Interface

CNMP – Conventional Network Management Protocol

MIB – Management Information Base

MN_i – Managed Nodes (i.e. Network Devices) where i = 1 to n

The Aglet Server (Tahiti) runs on every network device as the context server for incoming mobile agents. The agents are subject to security policies that are contained in the Modified Multi-signcryption protocol (MMSP) designed in this work. The arriving agents are authenticated and there after communicate with SNMP agent via UDP packets. The advantage of this process is that no actual traffic is generated at all since the sockets are directed towards the 'loopback' device. At the end of the mobile agent task on the station, it dispatches itself to the next destination on its itinerary. Finally, the agent is disposed of at the end of its tasks.

An attacker may tamper with the agent (aglet) state and must be protected against an eavesdropping attack as it will contain sensitive administrative information. Hence, the agent data state are protected in order to provide authentication and confidentiality using the protocol described in subsequent sections.

3.1 Security Issues

Despite the attraction of mobile agent technology, security is still a major concern. Security is an even more important issue when the critical data is carried by a mobile agent ([11], [12]). Indeed, while agents can be used to extract data for query purposes, the agents are prone to attack and hence the security of data in the agent is of prime concern [13]. One important issue is the malicious agent problem, where an agent that executes on a host attacks other agents or local resources. A second security concern is the malicious host problem [14]. An agent is under complete control of its host, which may steal or modify agent information or even destroy the agent. The solution is to prevent the information from being disclosed to a host using robust secure protocol.

Most of the research work into security is concentrating on the malicious agent issue, by advancing techniques that isolate the execution of agent from the rest of the system. However isolating on its own is only a first step for security. A security framework for agent architecture must furnish further properties. It is important that agent that visits a trustworthy host must be able to authenticate the information that it furnishes. Again, a host that sends an agent out must possess ways to ensure that agent gets to their destinations unaltered [15].

The fact that SNMP uses the unreliable, connectionless UDP rather than reliable, connection-oriented TCP reduces its security. An attacker can masquerade as a management station or a network device and send out malicious UDP packets to the well-known SNMP ports (161, 162) or corrupting ongoing SNMP request-response sessions [16].

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The core of our secure agent system builds a protocol that is called Multi-signcryption protocol that provides user authentication, integrity and confidentiality for the agent transactions and Agent Transfer Protocol (ATP) over the network. The multi-signcryption protocol is a cryptographic method that fulfills both the functions of secure encryption and digital multi-signature for multi-users, at a cost smaller than that required by multi-signature-then-encryption ([17]; [13], [18]).

In [17], the author proposed a multi-signcryption protocol which combined a multi-signature with the encryption function. However, since their protocol can not provide message confidentiality, it cannot prevent a malicious attacker from obtaining the information in the messages. Pang [13] proposed a modified multi-signcryption protocol to achieve message confidentiality. However, since their protocol fixes the order of multi-signers beforehand, it does not satisfy the need for order flexibility. Moreover, it cannot provide non-repudiation. Seo [18] analyzed the weaknesses of these previous multi-signcryption protocols and proposed a new multi-signcryption protocol. Their protocol provides not only message confidentiality, non-repudiation and order flexibility but also other requirements for secure and flexible multi-signcryption. It is believed to be more efficient. Therefore, in this work, we adapt modified Seo multi-signcryption protocol referred to in this work as MMSP and use it to design our secure mobile agent protocol.

3.1.1 Initialization and notations

Let p, q be sufficient large primes with p = 2q + 1, and let $G \in Z_p^*$ have order q. Each managed node MN_0, MN_1, …., MN_n generates a pair of asymmetric key pairs (x_i, y_i), where $x_i \in Z_p^*$ and $y_i = g^{x_i} \bmod p$, and publishes the public key y_i along with its identity information ID_i through a Certificate Authority (CA). The MA itinerary (itireq corresponds to M_0) represents the original itinerary used to query or collect information from other managed nodes. Other notations used are stated below:

- MN_i : the i-th network gateway which belongs to the i-th managed node
- SMARTREN : the management center of an apartment complex
- NET : the network environment
- $E_{a,b}$: an elliptic curve over a finite field $GF(p^m)$, either with $p \geq 2^{150}$, $m = 1$ or $p = 2$, $m \geq 150$ ($E_{a,b}$: $y^2 = x^3 + ax + b (p > 3)$, $E_{a,b}$: $y^2 + xy = x^3 + ax^2 + b (p = 2)$, $4a^3 + 27b^2 \neq 0 \pmod p$))
- q : a large prime number whose size is approximately of $|p^m|$
- G : a point with order q which is chosen randomly from the points on $E_{a,b}$
- $ENC_K(\cdot), DEC_K(\cdot)$: the encryption and decryption algorithms of a private key cipher system with the key K
- $H(\cdot)$, $hash(\cdot)$: a one-way hash function
- x_i : the secret key of the i-th manager who uses the MN_i, $x_i \in R [1, ..., q - 1]$
- Y_i : the public key of the i-th manager who uses the MN_i, $Y_i = x_i G$
- ‖ : denotes concatenation

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3.1.2 Basic solution

In this section, we present a basic solution for secure network management services by applying an EC based signature protocol to SNMP based Context Servers (CS). We append the EC-DSS (Elliptic Curve based Digital Standard Signature) scheme [19] to the existing Network Management System (NMS) for user authentication and integrity of data. We assume that the existing NMS already establishes a common secret key K_i between MN_i and the Aglet (Tahiti) server of the Managed Nodes, and provides confidentiality through a private key cipher algorithm with K_i. Our basic solution is as follows.

[**EC-DSS Generation and Encryption phase**]

1. MN_i generates a signature on the itinerary data M_i as follows:
    a. MN_i chooses random $k_i \in R$ [1, ..., q − 1], and computes $r_i = k_i G \pmod q$
    b. MN_i computes $s_i = (H(M_i) + r_i x_i) \cdot k_i^{-1} \pmod q$
2. MN_i encrypts M_i with K_i, i.e., it generates $C_i = ENC_{Ki}(M_i)$.
3. MN_i sends (r_i, s_i, C_i, ID_i) to the SMARTREN.

[**EC-DSS Verification and Decryption phase**]

1. After the CS receives (r_1, s_1, C_1, ID_1), (r_2, s_2, C_2, ID_2), ...,(r_n, s_n, C_n, ID_n) from network gateways, it decrypts the C_i and obtains the itinerary data M_i of MN_i.
2. CS verifies the signature (r_i, s_i) of MN_i as follows:

(a) CS computes $r_i' = (H(M_i)G + r_i Y_i) \cdot s_i^{-1} \pmod q$.

(b) CS checks $r_i = r_i'$.

4.0 SMARTREN Protocol Using EC Multi-signcryption

In this section, we used a secure mobile agent protocol for network management services in network environments. Our protocol consists of four procedures such as registration procedure, mobile agent creation procedure, mobile agent execution procedure, and mobile agent arrival procedure. It provides confidentiality and integrity for the itinerary data, and user authentication using EC Multi-Signcryption. An overview of the proposed security model of the SMARTREN protocol is shown in Figure 2.

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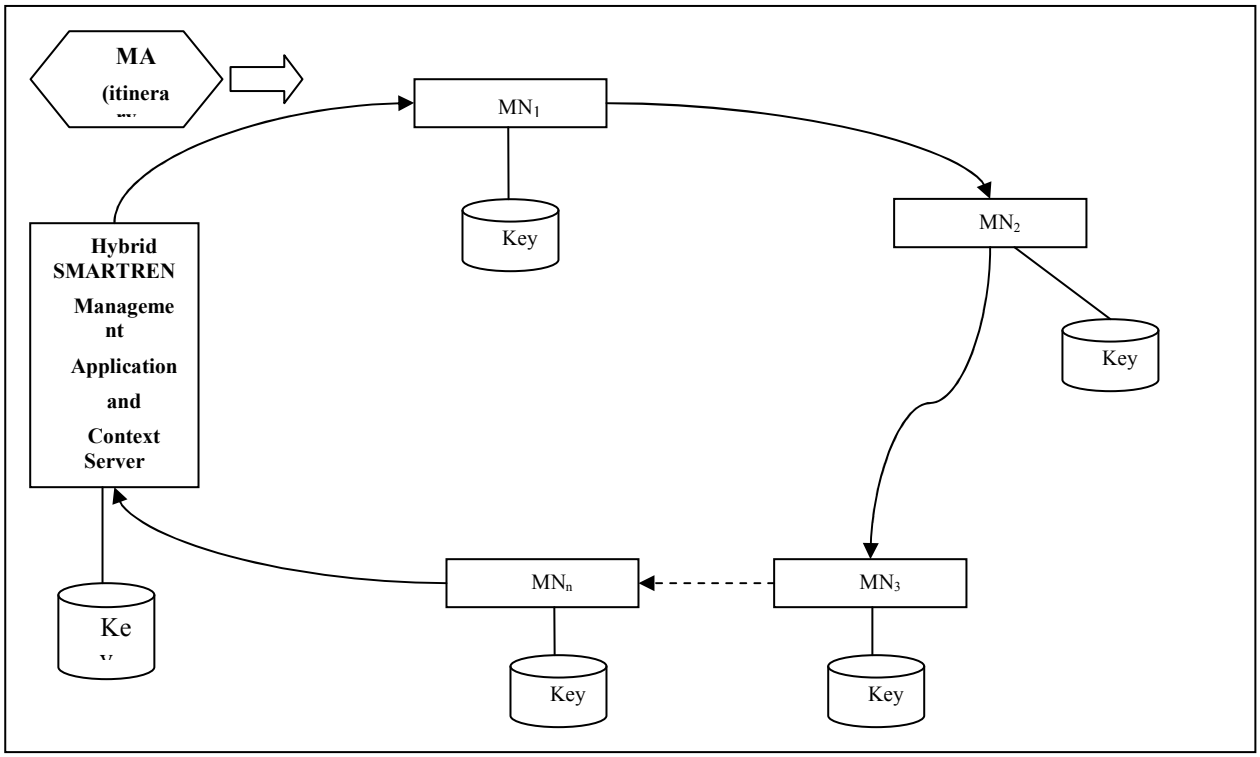

Figure 2: Security Model for SMARTREN Protocol

4.1 Certification procedure

In this procedure, each manager $U_i(1 \leq i \leq n)$ registers his own public key and address at the management center, SMARTREN.

1. U_i gives his public key certificate and address information to the SMARTREN.
2. After the SMARTREN checks U_i's identity and address, it stores U_i's identity ID_i, public key Y_i, address, and MN_i information in the database of the CA (Certification Authority).

4.2 Preparation and creation procedure

In this procedure, the SMARTREN calls a mobile agent MA and determines the migration path of MA, $MA_{route} = MN_1||MN_2||...||MN_n$. Then it creates itinerary request message itireq, and generates a signature on itireq as follows:

1. SMARTREN chooses random number $k_C \in R [1, ..., q - 1]$ and computes $R_C = k_C G$.
2. SMARTREN computes $r_C = H(itireq||ID_C||R_C) \pmod q$ and $s_C = (x_C + r_C) \cdot k_{-1}^{C} \pmod q$.

SMARTREN gives itireq, MA_{route}, and signature, (ID_C, r_C, s_C) to the MA, and the MA migrates to the first manager's network gateway, MN_1 with them.

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4.3 Execution procedure

1. After the MA has migrated to $MN_i (1 \le i \le n)$, MN_i checks the itireq and MA_{route}.
2. MN_i verifies the SMARTREN's signature and generates the EC Multi-Signcryption on its itinerary data, M_i as follows:

[**Verification phase of the SMARTREN's signature**]

(a) MN_i computes $R'_C = s_C^{-1} \cdot (Y_C + r_C G) = s_C^{-1} \cdot (x_C + r_C)G = k_C G$.

(b) MN_i checks whether $H(itireq||ID_C||R'_C) \pmod q = r_C$, or not. If the equation holds, then it performs the following EC Multi-Signcryption phase. Otherwise, it reports the failure to the SMARTREN.

[**EC Multi-Signcryption phase**]

(a) MN_i chooses $k_i \in R [1, ..., q-1]$, and computes a session key $K_i = hash(k_i \cdot Y_C) = hash(k_i \cdot x_C G)$ by using the SMARTREN's public key and k_i.

(b) MN_i computes the signature $r_i = H(M_i||ID_i||K_i) + r_{i-1} \pmod q$ and $s_i = (x_i + r_i) \cdot k_i^{-1} \pmod q$ by using received $r_{i-1} (1 \le i \le n, r_0 = r_C)$ from MA. And, it generates $C_i = ENC_{Ki}(ID_i||M_i)$ by encrypting (ID_i, M_i) with K_i. The EC Multi-Signcryption message is composed of the multi-signature (r_i, s_i) and the cipher text C_i. (r_i, s_i) are for user authentication and the integrity of M_i, and C_i is for the confidentiality of M_i.

3. MN_i gives the EC Multi-Signcryption message (ID_i, r_i, s_i, C_i) to the MA. Here, $r_i (1 \le i \le n)$ is connected to r_{i-1}. So, if the SMARTREN knows only r_n of the last signer, MN_n, then it can compute r_i of the previous signers, $MN_i (1 \le i \le n-1)$. Therefore, the MA removes r_{i-1} from (ID_1, s_1, C_1), ..., $(ID_{i-2}, s_{i-2}, C_{i-2})$, $(ID_{i-1}, r_{i-1}, s_{i-1}, C_{i-1})$, and it stores (ID_i, r_i, s_i, C_i).
4. If i = n, then MA migrates from the MN_n to the SMARTREN. Otherwise, the MA migrates from the MN_i to MN_{i+1}.

4.4 Arrival Procedure

After the MA finishes the travels of the migration path MA_{route}, it arrives at the SMARTREN.

1. MA gives (ID_1, s_1, C_1), ..., $(ID_{n-1}, s_{n-1}, C_{n-1})$, and (ID_n, r_n, s_n, C_n) to the SMARTREN.
2. SMARTREN performs the following EC Multi-UnSigncryption to verify and decrypt the EC Multi-Signcryption message.

[**EC Multi-UnSigncryption phase**]

(a) For i = n, ..., 3, 2, 1, SMARTREN computes the session key K'_i using its private key x_C, MN_i's public key Y_i, and (r_i, s_i).

i. SMARTREN computes $u_i = x_C \cdot s_i^{-1} \pmod q$ and $K'_i = hash(u_i \cdot r_i G + u_i Y_i) = hash((r_i + x_i) \cdot u_i G) = hash(x_C k_i G)$.

If $K'_i = K_i$, then the SMARTREN can decrypt C_i. And it can obtain the itinerary data M_i and ID_i of the MN_i.

ii. SMARTREN computes $r_{i-1} = r_i - H(M_i||ID_i||K'_i) \pmod q$. If the signature, r_{i-1}, is recovered then the SMARTREN lets i = i − 1 and performs steps i and ii again.

(b) If the verification is finished correctly then the SMARTREN can confirm its own signature, $r_C (= r_0)$.

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3. If the EC Multi-UnSigncryption phase is performed successfully and all itinerary data M_1, ...,M_n of MN_1, ..,MN_n are decrypted, then the SMARTREN stores M_1, ...,M_n.
4. SMARTREN terminates the MA's execution.

5. Analysis of the SMARTREN Protocol

In this section, we analyze the security of our mobile agent protocol according to the security requirements of message confidentiality, message integrity, user authentication, non-repudiation, and robustness. Then we analyze the efficiency of our protocol in comparison with the basic solution.

5.1 Security Analysis

1. **Message Confidentiality**: Message confidentiality means that it is computationally infeasible for a malicious attacker to gain any partial information on the content of the EC Multi-Signcryption message. In our protocol, if an attacker intercepts the mobile agent, MA, and searches the data in MA, then he can obtain the EC Multi-Signcryption messages (ID_1, s_1, C_1), (ID_2, s_2, C_2), ..., (ID_n, s_n, r_n, C_n) of the itinerary data M_1,M_2, ...,M_n. And the attacker can compute $s_i^{-1} \cdot (r_i \cdot G + Y_i) = k_iG(1 \leq i \leq n)$ from the EC Multi-Signcryption messages. But, since the attacker cannot know SMARTREN's private key, x_C, he cannot compute session keys due to the difficulty of the elliptic curve discrete logarithm problem [19]. Therefore, it is computationally infeasible for the attacker to gain any information of the itinerary data, M_1, M_2, ..., M_n. Our protocol provides confidentiality for the itinerary data.

2. **Message Integrity**: Message integrity means that the communicated EC Multi-Signcryption messages cannot be manipulated by unauthorized attackers without being detected. Assume that a malicious attacker modifies MN_i's itinerary data and tries to forge MN_i's ($1 \leq i \leq n$) EC Multi-Signcryption message, (ID_i, r_i, s_i, C_i). The attacker can create the forged itinerary data M_i' by modifying M_i of MN_i. And then, he chooses $k_i' \varepsilon_R [1, ..., q-1]$ and can compute the session key $K_i' = hash(k_i' \cdot Y_C) = hash(k_i' \cdot x_CG)$ by using the SMARTREN's public key and k_i'. Moreover, the attacker can use the r_{i-1} by eavesdropping on the MA, and he can generate signature $r_i' = H(M_i' ||ID_i||K_i')+r_{i-1} \pmod q$. But, since the attacker cannot know the U_i's (managers') private key x_i, he cannot compute $s_i' = (x_i + r_i') \cdot k_i'^{-1} \pmod q$. Even if he chooses a random x_i' and computes $s_i'' = (x_i' + r_i') \cdot k_i'^{-1} \pmod q$, the SMARTREN can verify that s_i'' is forged signature in the EC Multi-UnSigncryption phase. Therefore, the attacker cannot modify the itinerary data and cannot forge the EC Multi-Signcryption message. So, our protocol provides integrity for the itinerary data.

3. **User Authentication**: User authentication means the process whereby one party is assured of the identity of the second party involved in a protocol, and of whether the second party has actually participated. In our protocol, the SMARTREN can confirm the identity of the Administrator, U_i, through the ID_i included in the EC Multi-Signcryption message. In the EC Multi-UnSigncryption phase, the SMARTREN can assure that U_i actually participated. So, our protocol provides user authentication.

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4. **Non-repudiation**: Non-repudiation means that neither Administrators nor the SMARTREN can falsely deny later the fact that he generated an EC Multi-Signcryption message. In our protocol, non-repudiation is provided as follows. Since each EC Multi-Signcryption message includes the administrator Ui's ($1 \leq i \leq n$) private key, x_i, anyone who does not know x_i cannot generate an EC Multi-Signcryption message instead of U_i. Therefore, if MN_i of U_i generates the EC Multi-Signcryption, he cannot falsely deny later the fact that he generated it.

5. **Robustness**: Robustness means that if the signature verification on a message fails, then it prevents such unauthentic messages from damaging a receiver. In our protocol, after the SMARTREN receives the EC Multi-Signcryption message from the MA, if the verification of $K_i' = \text{hash}(x_C \cdot s_i^{-1} \cdot r_i G + x_C \cdot s_i^{-1} \cdot Y_i) = \text{hash}(x_C k_i G)$ fails, then the SMARTREN cannot compute the session key, K_i. So, since it cannot decrypt the cipher text C_i, it can prevent damage by an unauthentic message or malicious code in the MA. Therefore, our protocol provides robustness.

5.2 Efficiency Analysis

We evaluate our protocol from a point of view of network and communication overhead, and compare our protocol with the basic solution. We use the number of point multiple and modular multiplication to measure the computational cost, and the communicated message size to measure the communication overhead.

For convenience, we assume the following conditions:

(1) we denote the number of managed node gateways by n and the message size by |M| bits;

(2) the size of q is set to 160 bits;

(3) the output size of the cryptographic hash functions is 160 bits.

In the basic solution, since all MN_is transmit EC Multi-Signcryption messages (ID_i, r_i, s_i, C_i)($1 \leq i \leq n$) to the Aglet (Tahiti) Server of the SMARTREN at the same time, a network bottleneck can be happened. The total communication overhead of the basic solution is $n \cdot |M| + n \cdot |q| + n \cdot |H(.)| = n \cdot (|M| + 320)$. But, in our protocol, the total EC Multi-Signcryption messages from MN_1 to MN_n are (ID_1, s_1, C_1), ..., (ID_{n-1}, s_{n-1}, C_{n-1}), (ID_n, r_n, s_n, C_n), and the communication overhead is $n \cdot |M| + (n + 1) \cdot |q| = n \cdot (|M| + 160) + 160$. So, when compared with the basic solution, our protocol reduces the communication overhead to, at most, 50%. The amount of EC Multi-Signcryption messages to be stored in the Aglet (Tahiti) Server can also be reduced to, at most, 50%. Moreover, since the MA migrates autonomously and transfers EC Multi-Signcryption messages either between MN_i and MN_{i+1} or between MN_i and the Aglet (Tahiti) Server, the total remote interaction and network traffic can be reduced between them.

In the network overhead cost of our protocol and the basic solution, the point multiple is 1 for MN_i($1 \leq i \leq n$) and 2n for the Aglet (Tahiti) Server. In the case of 160-bit modular multiplication, our protocol is 1 for MN_i($1 \leq i \leq n$) and 2n for the Aglet (Tahiti) Server, but the basic solution is 2 for MN_i($1 \leq i \leq n$) and n for the Aglet (Tahiti) Server.

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We have, so far, assumed that the same secret key K_i established previously between the $MN_i(1 \leq i \leq n)$ and the Aglet (Tahiti) Server in the basic solution, and evaluated the efficiency of the basic solution without computational and communication costs for key establishment. However, key establishment is complex; it results in heavy network and communication overhead. If the secret key is fixed in the basic solution, "key freshness" cannot be provided. If the basic solution simply refreshes the secret key periodically, then it can provide "key freshness." But it has another security problem, i.e. it cannot provide "forward secrecy" or "backward secrecy", and it is not secure against "known-key attack" [19]. Therefore, if we add a key establishment phase to the basic solution for overcoming these security problems, then the computational cost and communication overhead of the basic solution increase, and the efficiency decreases.

Unlike the basic solution, our protocol does not need a key establishment phase. So, our protocol is more efficient than the basic solution.

5.3 Scalability

We compared two different solutions for sending itinerary data on managed elements to test network overhead imposed by the SMARTREN. SMARTREN is compared to the centralized SNMP using AdventNet SNMP. The topology used on this experiment consists of one management station and three managed nodes (DemoREN: RENa; RENb; RENc) interconnected through a 100Mbps Ethernet LAN. All machines run Windows or Linux. The daemon snmpd, which is included in the Linux, is an SNMP agent that responds to SNMP request packets.

In order to evaluate the performance, we alternately repeat the elements using the itinerary {RENa, RENb, RENc, RENa, etc.}. The SMARTREN approach fetches the SNMP table and does some filtering based on the user's requirement. The SMNP is implemented using AdventNet SNMP package. The manager sends SNMP UDP packets to a SNMP agent that responds to the REN manager. The manager sends requests to all elements to be managed; one after the other. Thus, a new request is started after receiving the response from the previous one, until the last node receives a request and sends the response to the manager.

The response time of SMARTREN is measured as the mean time of the MA launching time and returning time. The centralized SNMP approach is measured as the mean time of the first GET message was sent out and the last result fetched back.

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The following table listed the testing result:

	Centralized SNMP Approach	SMARTREN
1 host	0.69 Seconds	0.71 Seconds
2 hosts	0.9 Seconds	0.95 Seconds
4 hosts	1.2 Seconds	1.24 Seconds
30 hosts	4.9 Seconds	4.89 Seconds

Table 1: Response Time of SNMP and SMARTREN

From the table 1, the SNMP is a bit less when the hosts are small in performing the tasks. This is due to the fact that the SMARTREN is built on better architecture for handling mobility.

Regarding the health function computation, the SMARTREN daemon agent transfer less number of messages comparing to the SNMP method as shown in table 2. Thus, the total message size is reduced and the bandwidth is saved.

	SNMP		SMARTREN Daemon Agent	
	No. of Messages	Total Message Size	No. of Messages	Total Message Size
Interface utilization	4	364Byte	1	35Byte
Interface Accuracy	3	275Byte	1	34Byte
IP Discard Rate	5	458Byte	1	37Byte

Table 2: Communication Overhead of SNMP and SMARTREN Daemon Agent

Conclusion

This work has presented a framework to design a hybrid model based on secure mobile agent protocol and SNMP strategies. The work gives REN administrators flexibility of using any of the two approaches to exploit mobile agent technology in sharing resources. The results show that as the managed nodes increases, the proposed techniques perform better than conventional approach. On this note, this paper has demonstrated that it is possible to develop a secure mobile agent NREN management system using Java components and cryptography. To this end, the paper has presented reasonable detail on design level view.

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